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RADIOECOLOGY AND ECOPHYSIOLOGY OF DESERT PLANTS AT THE NEVADA TEST SITE

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Personnel from Division of Biology and Medicine, Civil Effects Test Organization, and Nevada Operations Office have contributed immensely to the work reported in this volume and their efforts are appreciated. The interests and encouragement of colleagues in other universities are also recognized. In addition the efforts of our collaborators must be acknowleged. Without their efforts the work would have been impossible.

In certain respects this volume is a review of literature but the bibliography is by no means complete. In July 1971 an international symposium on shrubs held in Logan, Utah, summarized a great amount of literature on desert plant ecology. That report will be available shortly and it should add greatly to the available information on this subject.

We recognize our limitations in attempting to describe a broad spectrum of information; in some cases our knowledge of subjects covered is largely preliminary and there are many gaps in that knowledge. In several of the individual sections of this volume a question is raised but no answer is given. We hope that future studies will add both depth and breadth to the work which we have started. Hopefully, future work will also correct any errors of fact or interpretation which are now present.

The plant species nomenclature and authority for same is taken primarily from the reports of Dr. Janice C. Beatley (1965, 1969). Some departure is partly due to recent changes in nomenclature. We assume responsibility, however, for any errors in plant taxonomy which may occur in this work.

We thank Dr. David Goodall for reading the manuscript on shrub association.

The help of secretaries in the Department of Agricultural Sciences and Laboratory of Nuclear Medicine and Radiation Biology is acknowledged and appreciated.

PREFACE

This volume was not designed as a comprehensive ecological or botanical treatise for the Nevada Test Site. Rather the present work has been assembled as a base for future studies regarding radiation effects and radionuclide and mineral cycling problems which are of interest to the Atomic Energy Commission and manipulation experiments such as those of interest to the International Biological Program. This volume also serves as a partial review of literature of topics of importance in meeting the needs of the programs listed. We hope that this initial effort will stimulate even more studies.

It is recognized that much of the information in this report is indicative of our background and experience and that of our colleagues. In a way this information contributes to an interdisciplinary approach to some of the environmental problems encountered at the Nevada Test Site. The disciplines of soil science, plant nutrition, statistics, horticulture, and plant physiology have been freely mixed as an approach to problems which are generally considered to be in the realms of ecology. We firmly believe that complex problems like those associated with the ecology of the Nevada Test Site can be solved only by an interdisciplinary approach. This is one reason why we are interested in the objectives of the International Biological Program.

The Nevada Test Site is a great natural outdoor laboratory, the potential of which has hardly been touched. The disturbances caused by testing programs present many opportunities for research under a variety of conditions. The diversity of natural systems at the Nevada Test Site makes possible a series of studies which can be almost unparalleled in importance. We hope that this present volume, which represents only a small portion of the biological work underway at the Nevada Test Site, adds something of value to the store of accumulating information concerning this great national resource.

We also hope that studies and reports which concern the Nevada Test Site can stand with other volumes such as "Environment of the Cape Thompson Region, Alaska" and "A Tropical Rain Forest" as contributions to an understanding of the effects of the nuclear age on ecosystems of the world.

Arthur Wallace
Evan M. Romney

NOMENCLATURE OF PLANTS FROM THE NEVADA TEST SITE THAT ARE USED IN THIS REPORT

This section contains an alphabetical listing of plant species used in this work. For several reasons it was deemed more convenient to use this procedure rather than giving authority for nomenclature with each topic. One reason was the difficulty of tabular presentations with the photoreduction method used in preparation of this book.

An attempt has been to make this list up to date. In some instances in the text explanations are given for recent changes but the text does not always conform to the recent changes. The sources most commonly consulted were Beatley (1965, 1969, 1971). References in the text were also made to works of Munz and Keck (1959), Munz (1968), Shreve and Wiggins (1964), and Benson and Darrow (1954). A few species listed do not occur at the Nevada Test Site.

- *Acamptopappus shockleyi* Gray
- *Allenrolfea occidentalis* (Wats.) Kuntze
- *Amsinckia tessellata* Gray
- *Antirrhinum filipes* Gray
- *Arabis pulchra* Jones
- *Artemisia arbuscula* Nutt.
    - subsp. *nova* (A. Nels.) Ward
  - *bigelovii* Gray in Torr.
  - *californica* Less.
  - *dracunculus* L.
  - *ludoviciana* Nutt.
    - subsp. *incompta* (Nutt.) Keck
  - *spinescens* D.C. Eat.
  - *tridentata* Nutt.
- *Astragalus lentiginosus* Dougl.
  - *purshii* Dougl.
  - *tidestromii* (Rydb.) Clokey
- *Atriplex canescens* (Pursh) Nutt.
    - subsp. *canescens*
  - *confertifolia* (Torr. & Frem.) Wats.
  - *hymenelytra* (Torr.) Wats.
  - *lentiformis* (Torr.) Wats. var. *giffithsii* L. Benson
  - *linearis* (Wats.) Hall & Clem.
  - *polycarpa* (Torr.) Wats.
  - *rosea* L.
- *Baileya multiradiata* Harv. & Gray
- *Bromus rubens* L.
- *Calycoseris wrightii* Gray
- *Caulanthus cooperi* (Wats.) Pays.
- *Ceanothus greggii* Gray
- *Cercidium microphyllum* (Torr.) Rose & Jtn.
- *Cercocarpus ledifolius* Nutt.
- *Chaenactis carphoclinia* Gray
  - *fremontii* Gray
  - *macrantha* D. C. Eat.
- *Chenopodium atrovirens* Rydb.
- *Chorizanthe brevicornu* Torr.
  - *rigida* (Torr.) T. & G.
- *Chrysothamnus nauseosus* (Pall.) Britton
  - *parryi* (Gray) Greene
  - *viscidiflorus* (Hook) Nutt.
    - subsp. *puberulus* (D. C. Eat.) Hall & Clem.
- *Coleogyne ramosissima* Torr.
- *Cowania mexicana* D. Don
- *Cryptantha circumscissa* (H. & A.) Jtn.
  - *nevadensis* Nels. & Kenn.
  - *recurvata* Cov.
- *Cuscuta nevadensis* Jtn.
- *Dalea fremontii* Torr.
- *Delphinium parishii* Gray
- *Descurainia pinnata* (Walt.) Britton
- *Dyssodia cooperi* Gray
- *Encelia virginensis* A. Nels.
- *Ephedra californica* Wats.
  - *funerea* Cov. & Mort.
  - *nevadensis* Wats.
  - *torreyana* Wats.
  - *viridis* Cov.
- *Eriogonum fasciculatum* Benth.
  - *inflatum* Torr. & Frem.
  - *maculatum* Heller
  - *nidularium* Cov.
  - *ovalifolium* Nutt.
  - *trichopes* Torr.
- *Eriophyllum pringlei* Gray
- *Eschscholzia glyptosperma* Greene
- *Eucrypta micrantha* (Torr.) Heller
- *Eurodium cicutarium* (L.) L'Her.
- *Eurotia lanata* (Pursh) Moq.
- *Festuca octoflora* Walt.
- *Franseria dumosa* Gray

  - eriocentra Gray
- Gilia cana (Jones) Heller
  - clokeyi Mason
  - transmontana (Mason & A. Grant) A. & V. Grant
- Grayia spinosa (Hook) Moq.
- Gutierrezia microcephala (DC.) Gray
- Haplopappus cooperi (Gray) Hall
- Hilaria jamesii (Torr.) Benth.
  - rigida (Thurb.) Benth. ex Scribn.
- Hymenoclea salsola T. & G.
- Ipomopsis polycladon (Torr.) V. Grant
- Juniperus osteosperma (Torr.) Little
- Kochia americana Wats.
- Krameria parvifolia Benth.
- Langloisia setosissima (T. & G.) Greene
- Larrea divaricata Cav.
  - tridentata Ses. & Moc. (replacing L. divaricata Cav.)
- Lepidium fremontii Wats.
  - lasiocarpum Nutt.
- Linanthus bigelovii (Gray) Greene
  - demissus (Gray) Greene
- Lupinus argenteus Pursh
- Lycium andersonii Gray
  - cooperi A. Gray
  - pallidum Miers
  - shockleyi Gray (L. rickardii C.H. Mull.)
- Lygodesmia exigua Gray
- Machaeranthera leucanthemifolia (Greene) Greene
  - tortifolia (Gray) Cronq. & Keck
- Malacothrix glabrata Gray
- Menodora spinescens Gray
- Mentzelia albicaulis (Hook) T. & G.
  - veatchiana Kell.
- Mirabilis bigelovii Gray
  - pudica Barneby
- Muhlenbergia porteri Scribn.
- Nama demissum Gray
- Nicotiana trigonophylla Dunal in A. DC.
- Oenothera megalantha (Munz) Raven
  - munzii Raven
  - primiveris Gray
- Opuntia basilaris Engelm. & Bigel.
- Oryzopsis hymenoides (R. & S.) Ricker
- Oxytheca perfoliata T. & G.
- Pectocarya platycarpa (M. & J.) M. & J.
- Peucephyllum schottii (Gray) Gray
- Phacelia fremontii Torr.
  - vallis-mortae J. Voss
- Plantago insularis Eastw.
- Poa nevadensis Vasey ex Scribn.
  - sandbergii Vasey
- Polygala subspinosa Wats.
- Prosopis juliflora (Sw.) DC. var. torreyana L. Benson
- Prunus fasciculata (Torr.) Gray
- Psilostrophe cooperi (Gray) Greene
- Purshia tridentata (Pursh) DC.
- Rafinesquia neomexicana Gray
- Salazaria mexicana Torr.
- Salix gooddingii Ball
- Salsola iberica Sennen & Pau (replacing S. pestifera A. Nels. det. by V. Botschantzev, 1970
  - paulsenii Litv. (S. kali L.)
  - pestifera A. Nels. (S. kali L.)
- Salvia leucophylla Greene
- Sarcobatus vermiculatus (Hook) Torr.
- Selinocarpus diffusus Gray
- Sitanion hystrix (Nutt.) J. G. Sm.
  - jubatum J. G. Sm.
- Sphaeralcea ambigua Gray
- Sporobolus airoides (Torr.) Torr.
  - flexuosus (Thurb.) Rydb.
- Stanleya pinnata (Nutt.) Britt.
- Stephanomeria exigua Nutt.
  - pauciflora (Torr.) Nutt.
- Stipa speciosa Trin. & Rupr.
- Streptanthella longirostris (Wats.) Rydb.
- Stylocline micropoides Gray
- Tamarix pentandra Pall.
- Tetradymia axillaris A. Nels.
  - canescens DC.
- Thamnosma montana Torr. & Frem.
- Thelypodium lasiophyllum (H. & A.) Greene
- Verbena bracteata Lag. & Rodr.
- Yucca baccata Torr.
  - brevifolia Engelm. in Wats.
  - elata Engelm.
  - schidigera Roezl ex Ortgies

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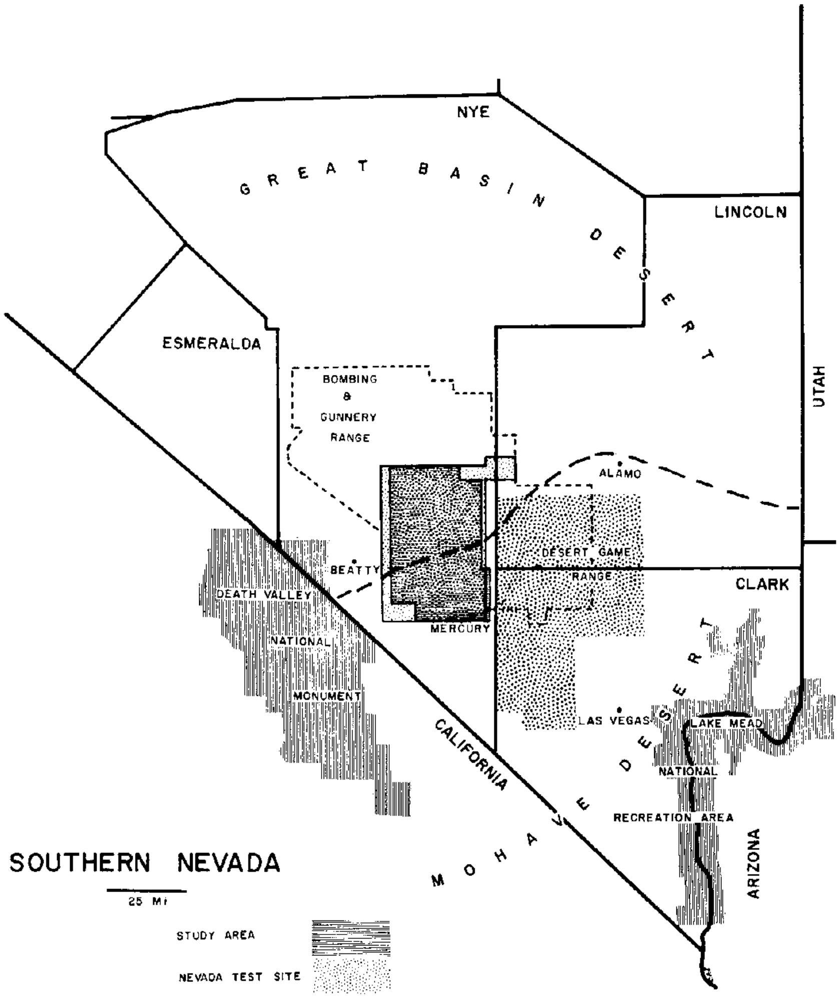
Appendix

INTRODUCTION

The Mojave Desert is a portion of the North American Desert lying to the south of the Great Basin Desert and north and west of the Sonoran Desert. The Mojave includes portions of southeastern California, southern Nevada, and extreme southwestern Utah. It embraces some of the most arid regions of the North American Desert. Life processes are dominated by the amount and time of distribution of rainfall and there may be pronounced year-to-year differences (as well as marked micro-geographical variation) in productivity.

Figure 1. Mojave and Great Basin Deserts. (Map courtesy of Dr. C. D. Jorgensen, Brigham Young University.)



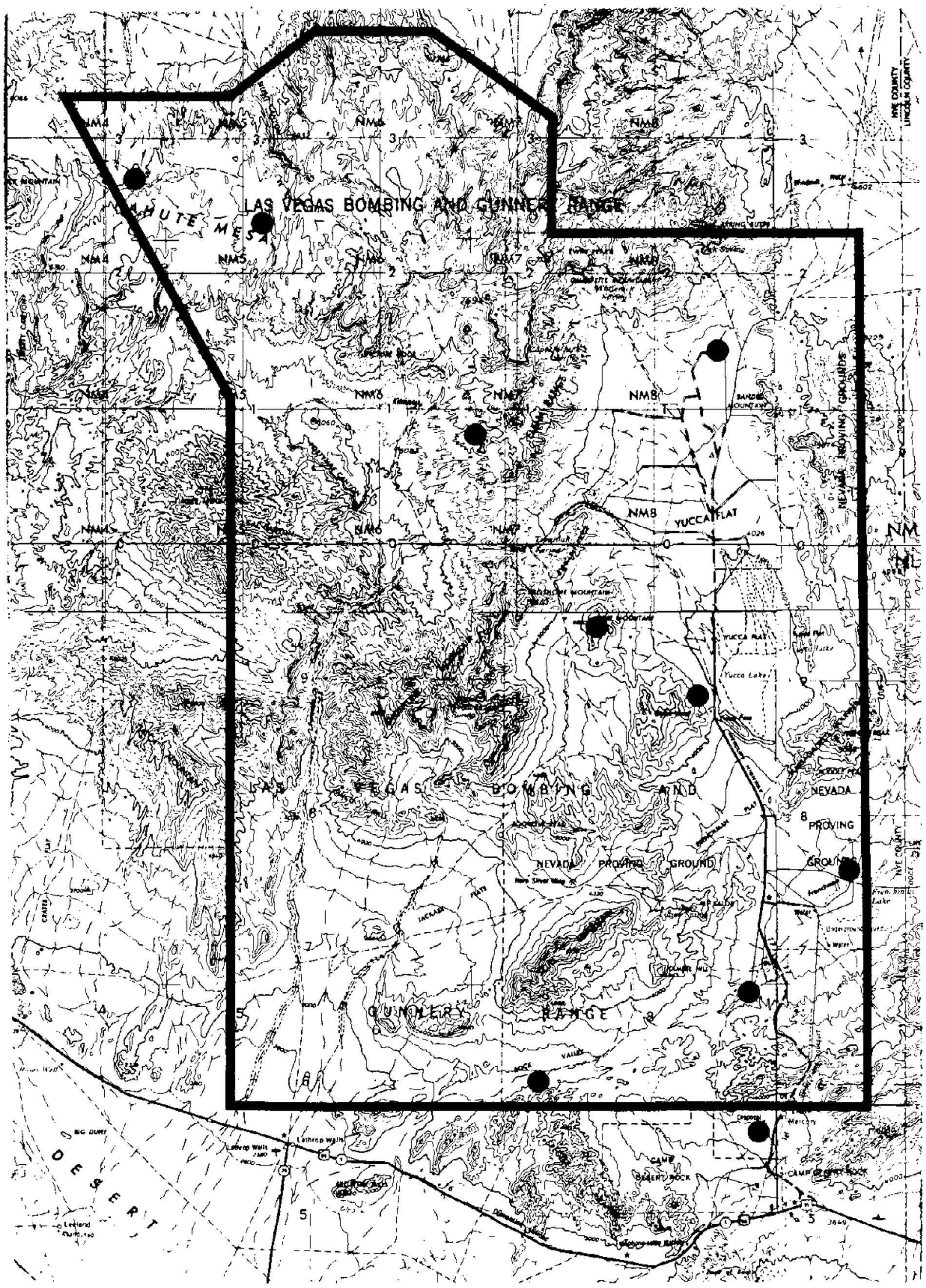


Figure 2. Nevada Test Site.

Within the transition zone between the Mojave and Great Basin Deserts lies the Nevada Test Site which comprises over 3000 sq km in southwestern Nevada (Figure 1). It is owned and operated by the United States Atomic Energy Commission. Access to it is through the community of Mercury, which is an installation controlled by the Federal Government. Mercury is about 100 km northwest of Las Vegas, Nevada, and just off U.S. Highway 95. The Nevada Test Site extends north about 100 km and about 30 km west of Mercury. Its elevation varies from 975 to over 2300 m. Drainage is partly into playas of closed basins and partly into Death Valley via the Amargosa Drainage Basin. Annual rainfall averages from 10 to 15 cm, most of which occurs in late winter. More important, there is considerable variation in year-to-year precipitation. Summer rains occur occasionally. Air temperatures range from below freezing to well over 37°C and are almost as irregular as rainfall in that large differences are encountered from year to year. Primary production is controlled by soil moisture in combination with air and soil temperatures; the primary production is divided between perennial shrubs and winter annuals. There are very few summer annuals.

Ecologically the Nevada Test Site lies in a transition zone between the Mojave and Great Basin Deserts with a large number of ecotonal variations from place to place depending upon elevation, drainage, slope exposure, temperature and edaphic factors. Beatley (1965, 1967, 1969) has a series of 68 study plots on the site, most of which are on essentially different types of vegetation. The shrub vegetation is Larrea-Franseria in the more typically Mojave Desert-type associations at lower elevations. Larrea-Lycium-Grayia is mostly at mid-elevations with Coleogyne on many of the upper bajadas. Artemisia-Pinyon-Juniper characterize the higher elevation Great Basin Desert-type associations.

Animals, including arthropods, of the Nevada Test Site have been collected, classified, and specimens preserved at various herbaria by investigators from Brigham Young University. The information has been documented in a reasonably large number of publications (see works of Allred, Jorgensen, Tanner and associates). Similar efforts for plants have been largely under the direction of Dr. Janice Beatley, University of California, Los Angeles, who has developed an herbarium of more than 12,000 entries of nearly 1100 species collected from, or near, the Nevada Test Site. Certain aspects of plant and animal ecology, and problems related to environmental contamination from radioactive fallout debris have been studied intensively for several years at the Nevada Test Site and at UCLA laboratory facilities (see works of Beatley, French, Larson, Martin, Nishita, Romney, Turner and Wallace).

One of the major ecological efforts of UCLA investigators has been in the Rock Valley area located near the southern boundary of the Nevada Test Site about 20 km west of Mercury, Nevada (Figure 2). This area was set aside by the USAEC specifically as a place where biological studies could be made on a long-time basis. Rock Valley is about 130 sq km in area and is more or less encircled by low mountains. Drainage from the valley is to the southwest into the Amargosa Valley. Within a fenced area in the valley is a 33,600 curie ^{137}Cs source, tower mounted, for the purpose of irradiating a 9-hectare plot having a relatively uniform chronic level of gamma radiation. The exposure ranges from 2 to 10 R per day within the fenced area except for periods when the source is stored underground to permit field work. Chronic radiation effects are being studied on small mammals, lizards, arthropods and plants. There are two fenced control plots of 9 hectares each, and a nonfenced control plot. Some other complementary plant and animal studies are being made outside the fenced areas in Rock Valley. Historically, the initial plans for a study of radiation effects on plant populations in Rock Valley were made by Dr. W. E. Martin in collaboration with R. A. Harvey (see appendix). Results from this study from February 1964 to July 1967 are included in the section, "An assessment of the seasonal growth on some desert shrubs subjected to chronic, low intensity gamma radiation." Within the Rock Valley area is another study plot of about 0.5 sq km in area which serves as one of the desert biome validation-study sites for the International Biological Program.

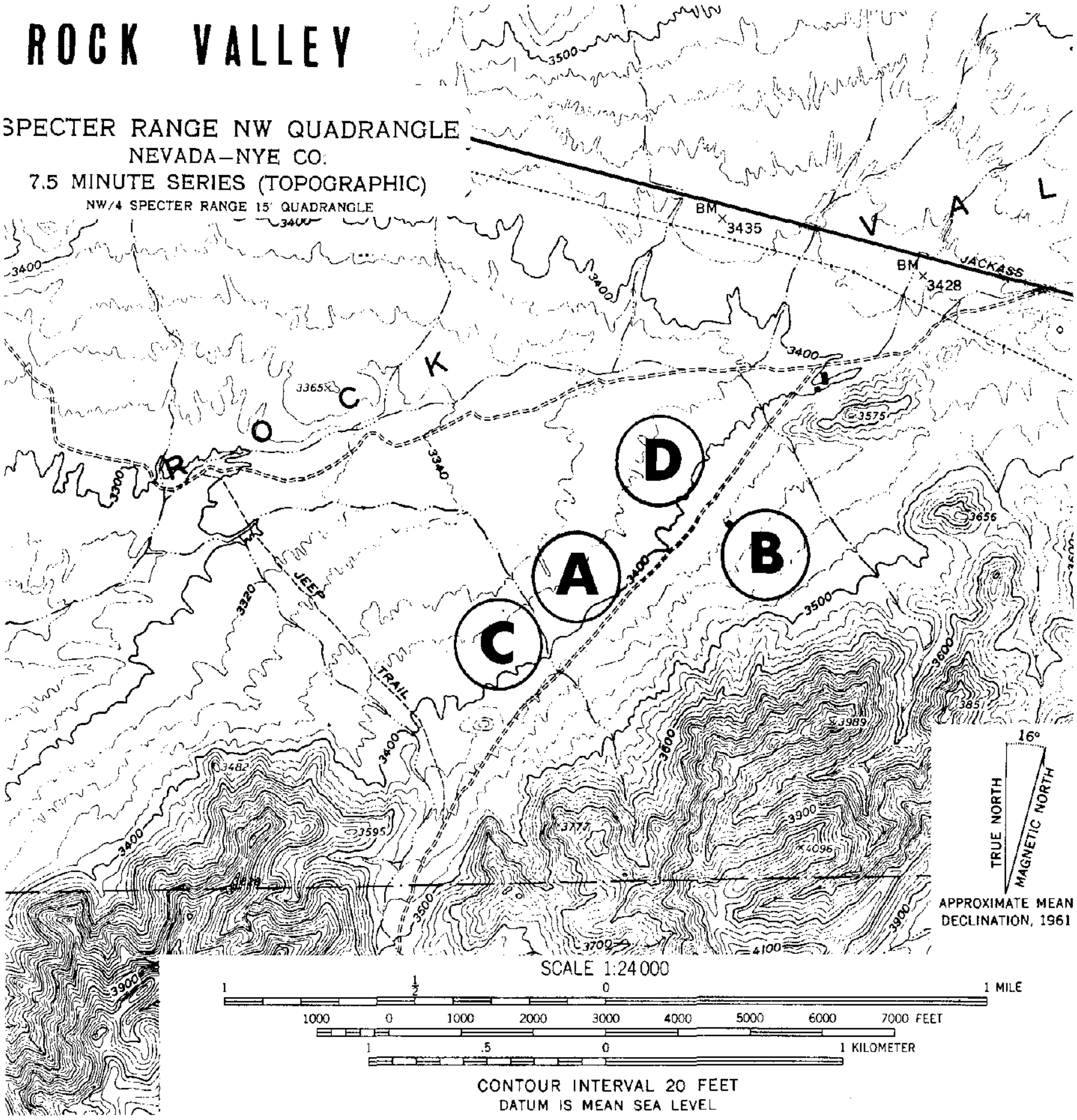
A smaller but intensive study area has been established near Mercury, Nevada, where irrigation, fertilization and other environmental manipulation studies are being conducted with a view of assessing the nature and magnitude of limiting factors of primary productivity. It is here also that considerable effort is being expended on studies of mineral cycling. Some additional soil and plant studies are being made in areas of Frenchman and Yucca Flats and at higher elevations around Pahute Mesa of the Nevada Test Site.

Soils at our more intensive study areas are derived from a heterogeneous, highly calcareous alluvium, composed primarily of Cambrian limestones. The soil surface is well developed desert pavement which is often underlain with a massive caliche hard-pan layer at depths ranging from 30 to 60 cm. Microrelief and soil profile structural features are responsible for several vegetation patterns. Perennial plants generally occur in discrete clumps containing from 2 to 5 different species, and these clumps host many species of annual plants with no apparent evidence of allelopathy. An intensive survey has been conducted to characterize and determine the physical and chemical properties of soils in our study sites and in other areas of pertinent interest. The nature and properties of these soils are the theme for another report in preparation.

EFFECTS OF A CHRONIC LEVEL OF GAMMA RADIATION FOR 5 YEARS ON SHRUBS IN THE NORTHERN MOJAVE DESERT

Several groups of workers have shown that irradiation of an ecosystem can result in differential injury to plant species and hence can result in changes in botanical composition of the system (Garrett, 1967; Platt, 1963; Rhoads et al., 1969; Woodwell and Sparrow, 1962).

Figure 1. Topography of Rock Valley study area with 9-hectare fenced enclosures. A 33,600 curie ^{137}Cs source is installed in plot B.



Since Sparrow et al. (1961, 1963) have shown that susceptibility to radiation injury is systematically related to nuclear volume, or more specifically to the interphase chromosome volume for different species, and since there is a wide difference in nuclear volume among the species involved in the desert ecosystem, it can be expected that wide differences in susceptibility to ionizing radiation would occur.

The Rock Valley research program out of which this particular study has developed was initiated as a comprehensive ecological investigation of the effects of chronic low level gamma radiation in a desert environment. Following earlier background studies, a 33,600 curie ^{137}Cs source was placed in the study area in the winter of 1964 (French, 1964).

The location of the study area is 20 km west of Mercury in Nye County, Nevada. It lies in the southwest corner of the U.S. Atomic Energy Commission's Nevada Test Site in the Rock Valley section (Figure 1). The elevation is about 1050 m and the slope is to the northwest with a gradient of 3 to 4 per cent. The study area approaches the limits of the northern Mojave Desert with some overlap with Great Basin plant species. Indigenous shrub composition is characterized by the following species with their per cent frequencies of approximately 5000 total shrubs per hectare: *Larrea divaricata* - 21%, *Lycium andersonii* - 22%, *Lycium pallidum* - 5%, *Franseria dumosa* - 17%, *Ephedra nevadensis* - 12%, *Krameria parvifolia* - 13%, and 10% other species (unpublished data of W. Martin). Plant taxonomy has been worked out by Beatley (1969). The soils are a highly calcareous alluvium with heavy, almost impenetrable "caliche" deposits lying from 35 to 50 cm below the surface.

The gamma radiation source is 33,600 curies of ^{137}Cs mounted atop a 15-m tower in plot B. Details of this source and its design were reported by Lucas et al. (1966). In order to achieve some uniformity of radiation exposure over the 9-hectare fenced plot, the source is subtended with a lead shield of differential thickness. The resulting radiation exposure at ground level is approximately 750 mR per hour 20 m from the tower and at the periphery of the plot, 170 m distant, exposure is 75 mR per hour. At 350 m from the tower the exposure is less than 10 mR per hour (Figure 2). The cumulative exposure at the time of this evaluation was 29 kR 20 m from the tower, 3 kR at 170 m and approximately 200 R at 350 m. This latter point is outside the fenced plot. The cumulative exposure time was 1636 days. The ^{137}Cs source is lowered into a heavy lead cask below ground about 5 days each month to permit entry for study purposes.

Field data obtained in these plots in the years 1964 to 1968 were subjected to multivariate analysis by species using Biomedical Computer Programs BMDX63, Multivariate General Linear Hypothesis of the Health Sciences Computing Facility (French, 1969). The variables simultaneously considered in each analysis were:

1. Increase in shoot length (mm).
2. Number of leaves per cm of shoot length.
3. Increase in lateral shoot length per cm of shoot length.
4. Number of flowers per cm of shoot length.
5. Number of fruits per cm of shoot length.

The results from this analysis indicated differences among years for each species and between plots for the species *L. divaricata*, *L. andersonii*, and *E. nevadensis* but not for *Grayia spinosa*, *F. dumosa*, or *L. pallidum*. Estimated nuclear volumes for these six shrub species, respectively, were 212, 466, 600 - 800, 128, 152, and 156. If one were predicting which of the six species

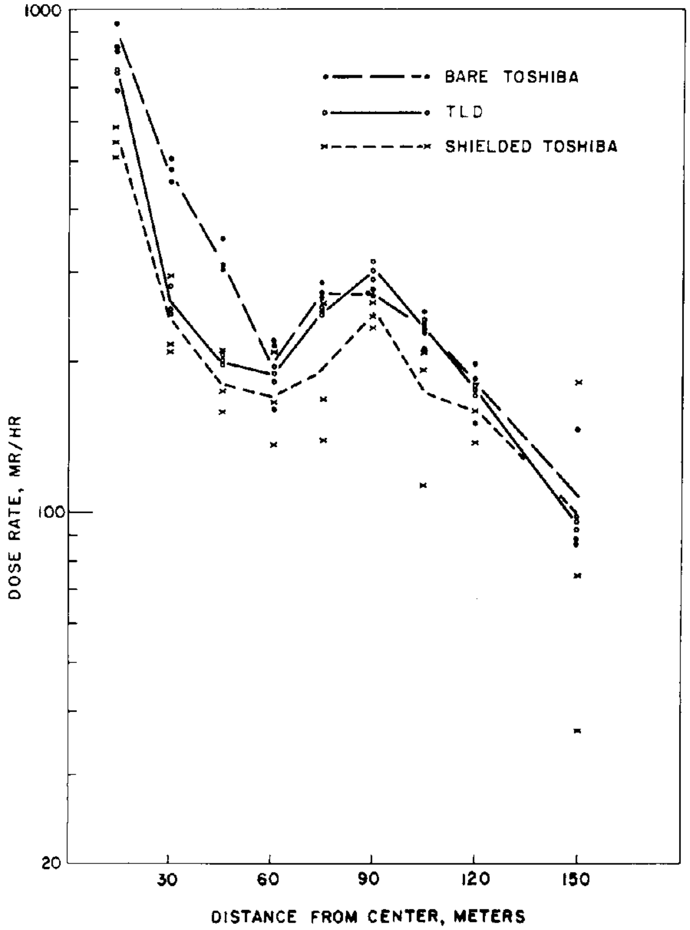


Figure 2. Radiation exposure at ground level along the radius of plot B. Dose rates were measured in August and September 1964. (Reprinted from UCLA Report 12-532 by N. R. French.)

might respond to the gamma radiation, those with the largest nuclear volumes would be chosen. The reasons for differences among years is easily explained by the pattern of rainfall (see appendix).

The variability of the data from which the multivariable analyses were made led us to suspect that some of the differences among plots were not real so additional comparisons were made in 1969.

Materials and Methods

The field work conducted in the plots in the spring of 1969 was designed to obtain additional information on those species having the largest nuclear volume which are the species with significant differences between plots in the previous study. For two species, L. andersonii and L. divaricata, a sample transect line was laid out extending northward and southward from the ^{137}Cs-source tower with three discrete locations being sampled at distances of 60, 152, and 335 m from the tower. Five plants of each of the two species were chosen at each location. Five shoot areas were marked on each plant and the shrub volume was measured. At appropriate times total flower counts were made for each shoot and, at a later date, fruit counts were made for these shoots. Fruits were then removed and counted, samples of seeds from each of the transect locations were reserved for viability testing. All plants taken were as closely clustered to the transect locations as possible. A total of 30 plants of each species were sampled. Care was taken in establishing the transect lines to maintain the same elevation and plants were picked from the same general soil type.

We then determined the percentage of flowers producing fruit and additionally tested the seed for viability.

Ephedra nevadensis, the species having the largest nuclear volume, was studied somewhat more intensely. With this species we compared plants in the irradiated plot with those growing in a control plot. We divided each of the two plots into parallel strips with alternating widths of 15 and 30 m. Every plant with 50 per cent or more of its ground cover lying inside the 15-m strip was sampled. Thus we effectively censused approximately one-third of all E. nevadensis plants in each plot. E. nevadensis is a dioecious species and counts were made to determine the number of staminate cones on each male plant. Ovulate cones were not sampled but fruit counts were made for all ovulate plants. Each plant was classified vegetatively as follows:

Poor - little or no new shoot growth
Fair - shoot growth sparse and less than 7 cm
Good - shoot growth heavy and many shoots 15 to 30 cm long
Very good - shoot growth luxuriant with many shoots in excess of 30 cm.

Experimental Results

The choice of 1969 for detailed studies of radiation effects was a good one for at least one reason. The rainfall in February and March 1969 was abundant (see appendix) and conditions following were very favorable for growth of shrubs. Over 20 cm of precipitation occurred from October 1968 through March 1969 and April and May had the highest mean temperatures for 7 years of record. A more favorable season had not been available for many years. These favorable conditions could be expected to allow any stress from radiation to become the limiting factor and consequently to be expressed. This proved to be the case for E. nevadensis. In some years growth can hardly be detected on this species but in 1969 the species grew extremely well except in the irradiated plot.

The results in 1969 for E. nevadensis show that the radiation had caused great differences in flowering, fruiting, and vegetative growth (Table 1). The results observed in the irradiated plot were not observed anywhere else on the test site and it must be concluded that the results were due to radiation. A greatly important aspect of the 1969 results is that it was a year conducive to large amounts of shrub growth and reproduction because of winter rains and favorable temperature conditions throughout the spring of 1969. The rainfall assured that soil moisture was above field capacity and not acting as a limiting factor in plant growth and reproduction.

Laboratory studies with E. viridis indicate that 2 to 3 kR of γ radiation as an acute dose greatly decreased vegetative growth (see page 109).

Table 1. Effect of 5 years of γ irradiation on some characteristics of *E. nevadensis* in the spring of 1969.

Condition of new growth	Plot B Irradiated	Plot D Nonirradiated	Chi square Probability of nonsignificance
	New vegetative shoot growth* (no. of plants)		
Poor	472	58	<.01
Fair	650	296	<.01
Good	505	1066	<.01
Very good	0	495	<.01
Total**	1627	1915	
No. of staminate cones on each plant	Cone production (staminate plants only) (no. of plants)		
25 or fewer	63	238	<.01
26 - 100	11	242	<.01
101 and over	3	208	<.01
Total no. with cones	77	288	<.01
No. of fruits on each plant	Fruit production (no. of plants)		
25 or fewer	19	238	<.01
26 - 100	1	169	<.01
101 and over	0	109	<.01
Total no. with fruits	20	516	<.01
	Summary of staminate cones and fruits		
Per cent with cones	4.8	35.9	<.01
Per cent with fruit	1.2	27.0	<.01

*For meaning of poor, fair, good, and very good see text.
**Includes both staminate and pistillate plants.

The results obtained in 1969 for *L. andersonii* were inconclusively related to radiation (Table 2). Laboratory studies with acute doses of γ radiation indicate that 4 to 7 kR are necessary to cause severe injury in the species (see page 67).

No radiation effects on flowering and fruiting of *L. divaricata* were evident in 1969 (Table 3). Acute doses of radiation for this species of around 10 kR have been shown to be necessary for injury (see page 67).

These results as well as those of Rhoads et al. (1969) concerning radiation from nuclear detonations indicate that shrub species can be differentially injured in a desert ecosystem by excessive amounts of ionizing radiation. The species *E. nevadensis* is common to the ecosystem studied by Rhoads et al. (1968) and the ecosystem in the present study. The results for both systems

Table 2. Effect of 5 years of γ irradiation on some characteristics of L. andersonii in the spring of 1969.

Location from γ source m	Mean vol. of shrub (mean of 5) m^3	No. of flowers per plant segment (mean of 25 segments)	No. of fruits per plant segment (mean of 25 segments)
West 60	0.57	54.0	14.2
East 60	0.74	65.0	7.8
West 152	0.82	56.9	8.0
East 152	0.87	79.9	45.2
West 335	0.45	61.8	28.2
East 335	0.25	55.5	17.9
F value	2.36*	4.26*	9.3**
LSD .05	0.46	12.8	13.0
LSD .01	N.S.	16.9	17.2

are similar. As in ecosystems studied elsewhere (Baylocks, 1967; Garrett, 1967; Platt, 1963; Rhoads et al., 1969; Woodwell and Sparrow, 1962) these results show that ionizing radiation can profoundly change an ecosystem by differentially removing some of the plant species.

Seeds collected in the spring of 1969 were tested for germination. Either two or four sets of 100 seeds for each species were planted in flats of vermiculite in a glasshouse and the number of germinating seeds were counted. The low percentage of germination was typical of other results obtained with these species in this laboratory. Six (3, 3) of 200 seeds of E. nevadensis from inside plot B (irradiated) germinated while 3 (0, 3) from inside plot D (nonirradiated) germinated. No seeds from a collection made randomly in Rock Valley from outside the study area germinated in the test. Eleven L. divaricata seeds (3, 0, 6, 2) of 400 from within 15 m of the source in plot B germinated. Seventeen (6, 5, 3, 3) of 400 seeds collected 160 m from the source germinated while 13 (2, 2, 6, 3) collected 335 m from the source germinated.

Table 3. Effect of 5 years of γ irradiation on some characteristics of L. divaricata.

Location from γ source m	Mean vol. of shrub (mean of 5) m^3	No. of flowers (mean of 25 shoots on 5 plants)	No. of seeds (mean of 25 segments on 5 plants)
West 60	0.55	45.6	42.0
East 60	1.97	44.7	32.9
West 152	0.71	45.6	41.0
East 152	0.93	60.5	51.7
West 335	0.59	47.6	35.2
East 335	0.51	52.1	49.8
F value	0.5	2.7*	2.2
LSD .05	N.S.	10.3	N.S.
LSD .01	N.S.	N.S.	N.S.

With L. andersonii 5 seeds (1, 1, 2, 1) from 15 m, 5 seeds (0, 3, 1, 1) from 160 m and 8 seeds (2, 2, 4, 0) from 335 m germinated. The results with these three species do not suggest an effect of radiation on the seed germination in the test. They suggest only that percentage germination for these species was very low and that assessment of the possible effects of radiation on germination of seed in this type of study would be extremely difficult to achieve.

Summary

A 33,600 curie ^{137}Cs source which was differentially shielded to increase the uniformity of the distribution of radiation was mounted on a 15-m tower in the center of a 9-hectare plot in January 1964 in the Rock Valley area of the northern Mojave Desert. In the spring of 1969 the large majority of approximately 5000 E. nevadensis within the plot failed to produce flowers and very little vegetative growth occurred in contrast to a control plot and to other non-irradiated areas. The cumulative radiation exposure throughout the plot ranged from 3 to 29 kR. Radiation effects on L. andersonii were uncertain and effects were doubtful on other species. E. nevadensis and L. andersonii have higher nuclear volume than do the other shrub species. Considerable resistance to gamma radiation is experienced for several of the other species given acute exposure under laboratory conditions.

AN ASSESSMENT OF THE SEASONAL GROWTH ON SOME DESERT SHRUBS SUBJECTED TO CHRONIC LOW INTENSITY GAMMA RADIATION*

The proliferation of nuclear weapons and the growing dependence on nuclear fuels to replace diminishing fossil fuels has created a new and serious dimension to the biological environment. The potential disruptive effects brought about by the increase of chronic levels of radiation in the biosphere have provided the stimulus for a great amount of research. Such investigation is of considerable academic interest, but the practical and far-reaching implications of these endeavors should not be overlooked.

Early biological studies at the Nevada Test Site were concerned with the gross effects on the ecosystem which resulted from the detonation of nuclear devices in the atmosphere (Larson et al., 1952, 1960; Lindberg et al., 1954). Although profound biological changes did occur over large areas as the result of these tests, the effects of radiation _per se_ on that ecosystem were technically impossible to separate from a number of other factors. The observed damage was clearly the result of multiple causes which included the overlapping effects of thermal radiation, blast, inundation, ground shock, and dust, as well as of nuclear radiation (Shields and Wells, 1962, 1963; Rickard and Shields, 1963; Martin, 1963; Beatley, 1965). The results of such studies, although important and of great interest, were limited relative to the fundamental question of chronic radiation effects on a natural desert community.

The Rock Valley project, of which this plant study is a part, was designed specifically to investigate the effects of chronic, low-intensity gamma radiation on a desert ecosystem. At this time it is unique. The fixed gamma source (33,600 curies ^{137}Cs) is differentially shielded to greatly reduce the normal "inverse square" distribution of radiation with distance (Lucas et al., 1966). The design of the tower and shield which supports the source, provides a reasonably uniform gamma level of 2 to 10 roentgens (R) per day, distributed over a fenced circular plot approximately 340 m in diameter.

These facilities were used for the plant study reported here. It is part of an integrated ecological study being conducted in this division. Reports covering mammal, lizard, and arthropod studies appear elsewhere (French, 1964, 1969; Turner et al., 1965, 1969; Turner and Lannon, 1968; French et al., 1966, 1967).

The data which provide the basis for this report were collected mostly by R. A. Harvey from February 1964 to July 1967. They consist of more than a half million individual observations made during the four growing seasons covered by the study. The assessment was based on precise monthly measurements of tagged terminal shoots on shrubs in the irradiated plot and in an adjacent non-irradiated control plot. The shrubs sampled represent the six species dominant in both plots. Seasonal morphological changes were numerically recorded and comparisons between species and plots were made to: (1) document the qualitative and quantitative responses of seasonal growth, (2) identify and quantitate the effects of chronic low level gamma radiation on the dominant shrubs.

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*This report was prepared by R. A. Harvey and the study originally designed by W. E. Martin (see page 392).

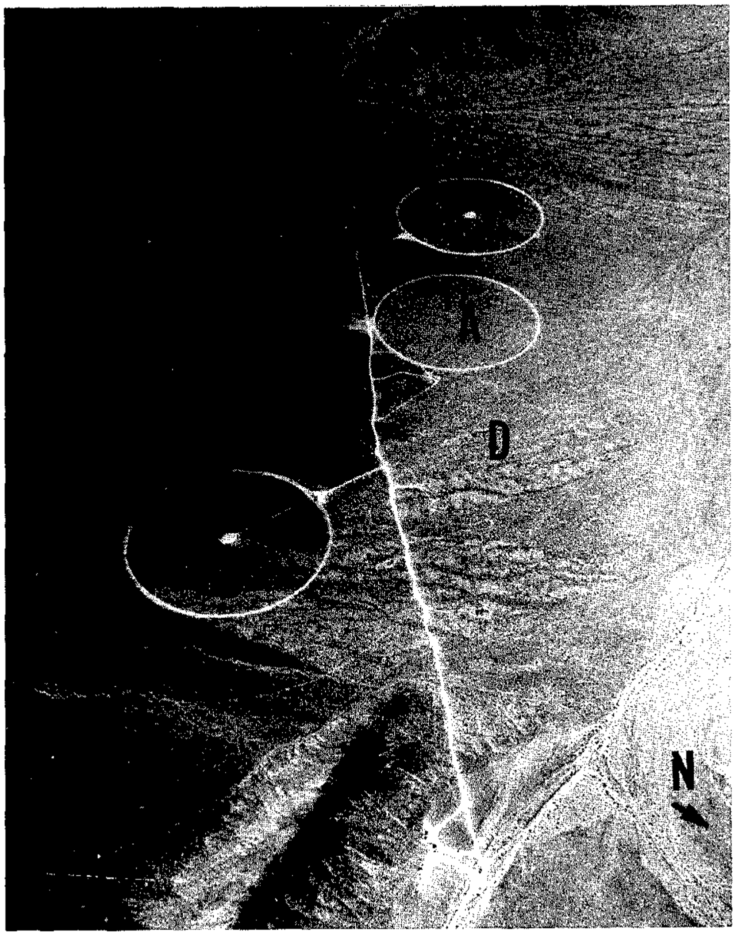
Description of Study Area

Topography

The gamma field (Plot B) and the control area (Plot D) in which these studies were conducted, are located on a broad alluvial fan bordering the northwest side of the Specter Range. The general location is Rock Valley, 20 km west of Mercury in Nye County, Nevada. The facilities are within a security area on land administered by the U.S. Atomic Energy Commission's Nuclear Test Site (Figure 1).

The average elevation of the study area is approximately 1050 m mean sea level. The slopes within the plots range from 3% to 4% and the initial drainage is toward the northwest. Subsequent drainage from the valley floor is toward the southwest into the Amargosa Desert drainage basin. In the lower portions of the study area are well-defined drainage channels and patches of bare, unusually structured soil surface called desert pavement.

Figure 1. View of study area in Rock Valley. Plot B is the gamma field. Plot D served as the control area for the plant study.



These factors of slope, drainage and desert pavement are responsible for a degree of vegetational heterogeneity which complicated the selection of an adjacent control area for the radiation study.

Soil

The soils in the study area are derived from a heterogeneous, highly calcareous alluvium. The parent material is principally Cambrian limestone from the Specter Range (Johnson and Hibbard, 1957). On the steeper slopes above the plots and in the shallower drainage channels which cross the study area, there has been little profile development. The soils on the gentler slopes have characteristic profiles.

Two soils have been characterized and their distribution has been mapped on the basis of surface characteristics (see page 394). Type I is a loose sandy loam which forms the principle soil surface in the study area. Type II is a loosely consolidated soil designated as "desert pavement" due to its unusual surface structure (Springer, 1958). Partial analysis of these soils appear on page 394.

Nearly all of the plants and the animal burrows are to be found in the abundant Type I soil. Its loose, broken surface affords easy penetration for the seeds of plants.

On the other hand, the islands of desert pavement, Type II, which are interspersed with the dominant soil are bare of vegetation and are only infrequently invaded by burrowing animals. The surface of this pavement is composed of flattened stones (1 to 4 cm diameter) lying close together with their long axis parallel to the soil surface. This forms a smooth, hard surface which gives the appearance of a tiled floor. These surface stones are embedded in a thin layer of fine loam having a definite vesicular structure. When the soil is wet, the surface yields to pressure in a sponge-like manner. The underside of the surface stones is encrusted with lime and the upper surface of these stones is frequently etched by erosion into bizarre patterns. Some desert varnish composed of material other than the parent limestone is present on pavement stones.

The profiles of both soil types are characterized by the downward movement and deposition of lime and other soluble minerals released by the weathering of surface rocks. Stones in that region designated as Horizon A have lime encrustations only on the undersides. Buried stones in Horizon B have lime coatings on all surfaces. The matrix soil in Horizon B has a weak, blocky structure.

The frequency of lime seams and nodules increases with depth, and heavy deposits generally below two feet form a massive, cemented caliche which underlies the entire area. In the deeper drainage channels, the caliche has been stripped of its overburden and lies exposed at the surface.

It is apparent that the shallowness of the soil which overlays this caliche is of fundamental importance to the plant community. With root penetration limited to soil above the caliche layer, there are obvious limits to the soil reservoir that these plants can draw upon regardless of the rainfall supplied throughout the season. Compared with adjacent areas in the Mercury and Frenchman drainage where the soil is deeper, the shrubs in the study area are smaller in size and contain considerable amounts of dead wood. It appears that stresses related to edaphic structure are largely responsible for the stunted appearance of the plant community in the study area in Rock Valley.

Vegetation and Phenology

The vegetation in the study area conforms to the general characteristics of the northern Mojave Desert (Allred et al., 1963). It is ecotonal in nature with species dominance not as clearly defined as in some adjacent areas. Great Basin species integrate from the northeast and the Rock Valley drainage approaches the northernmost extension of clearly defined Mojave flora.

A preliminary survey of the study area in 1963 (see page 396), using the Quarters Method of vegetational analysis (Cottam and Curtis, 1956) provided data which (1) formed the basis of community description, (2) revealed species dominance, and (3) established criteria for the selection of a suitable control area.

Prior to the initiation of the plant study, the irradiated plot (Plot B) had been selected and the hardware installed. The mammal and lizard studies were in progress. One of three possible control areas used in these studies had to be selected as an experimental control area for the plant study. In spite of some obvious topographic differences, Plot D was selected as the best choice based on species similarity to the plot with the gamma radiation field. Data derived from the Quarters Method of analysis showed a coefficient of similarity of 86 based on a calculation of importance value for the seven dominant species (see page 396). Species dominance as indicated by frequency, cover, density, volume, etc. in both plots was more completely defined by line intercept analysis (Canfield, 1941). Fifty lines, 15.2 m in length, were set out over the irradiated as well as the control plot (see page 393). These data formed the basis for selecting the six dominant shrubs typical of both plots for detailed study. These shrubs are (1) *Ephedra nevadensis*, (2) *Franseria dumosa*, (3) *Grayia spinosa*, (4) *Larrea divaricata*, (5) *Lycium andersonii*, and (6) *Lycium pallidum*. Illustrations of these shrubs appear in Figures 2 to 7. Other shrubs present are given on page 396.

In general appearance the community consists of scattered clumps of shrubs. These shrubs frequently consist of from two to five different species growing together. Per cent of ground surface covered by these shrubs was also determined by line-intercept analysis. Cover in Plot B was 23.4% and in Plot D was 22.7%. These data further revealed that 4.6% in Plot B and 9.1% in Plot D of the total plant intercept was covered by dead shrubs. In addition to those which were obviously dead, nearly all of the mature shrubs are composed of moderate to large amounts of dead wood. An infestation of *Cuscuta nevadensis*, a succulent parasitic herb commonly known as dodder, which flourishes in the area during unusually moist years, no doubt contributes substantially to this damage. This is particularly true of *L. andersonii*, *L. pallidum*, *G. spinosa*, and *F. dumosa* that appear to be especially susceptible host plants (see page 162). Selective die-back in all species due to other causes was also observed during the summer months throughout the study.

All six species selected for study, with the exception of *L. divaricata*, remain leafless and inactive throughout most of the year except for a relatively brief three- to five-month period between February or March and July. During years when sub-normal winter rains occur, little if any signs of spring growth appear. The first season of sampling, 1964, was such a year. Conversely, if conditions of soil moisture, temperature, and humidity are especially favorable, the onset of seasonal growth may begin early and continue well into the summer. On occasion, summer showers may initiate a brief second stage of growth indicated by shoot elongation in *L. divaricata* and the appearance of leaves on the deciduous species.

In dormancy, *L. pallidum* and *L. andersonii* are completely leafless.

Even the green, succulent appearance of new shoots sometimes following summer rains rapidly disappears. Seasonal response is almost explosive in these species. Within a few days after the first minute leaf buds appear in the spring, the whole shrub is covered with mature leaves and flower buds. Its summer decline is not as pronounced. Leaf buds are obviously retained in the nodal callus during dormancy. The expansion of these buds no doubt accounts for the rapid set of new leaves.

Dormancy with G. spinosa and F. dumosa takes a slightly different form. Although leaves are not carried in dormancy, external rosettes of leaf buds are retained giving the bare shoots a warty appearance. It is the unfolding of these rosettes that mark the onset of spring growth with the production of leaves and shoots.

The E. nevadensis in Rock Valley gives an almost continual appearance of dormancy. Even during a "good" year, many individual shrubs show little response. Growth in any single season is principally confined to some flowers and fruit and to lateral shoot production on certain branches. The only leaves are minute scale-like structures which appear briefly in a single pair at the nodes of growing shoots.

It appears that L. divaricata exercises great economy in that its leaves are retained throughout the year. Its response to dormancy appears to be physiological rather than mechanical. It also appears that this species will undergo shoot elongation and flower-fruit production whenever environmental conditions permit. Usually, however, this growth is confined to the same season as the other species, the one difference being that it starts later and finishes after most of the other species have gone into dormancy. It is interesting to note that the desiccated appearance of L. divaricata during the late summer and fall is visually and texturally alleviated by morning dew or rain. It seems that moisture is absorbed by the leaves although in insufficient amounts to initiate growth at that time. A second stage of growth in late summer is dependent upon available soil moisture and adequate temperature-humidity factors.

The annuals represented in the study area may be placed into two general categories. The majority of the species germinate between September and December after an adequate rainfall. Low temperatures restrict them to small rosettes until early spring when they begin a second stage of development which ends in flower and fruit production. The second type, represented by only a few species, germinates with summer rains and proceeds to full development during that time. For a fuller treatment of this phenomenon, see Beatley (1965). In all, the herbaceous flora of Rock Valley consists of one perennial grass (Oryzopsis hymenoides) and more than 50 herbaceous annuals (see page 230).

Most of the annuals are confined to the soft, protected richer soil at the base of the shrubs or in disturbed areas around the animal burrows. Normal distribution of annuals in the grids would be difficult to assess as the unavoidable foot traffic of investigators has in time caused changes in that thin strata of soil in which these plants exist. Soil disturbance of any kind has a potentially profound effect upon the micro habitat of these plants and consequently upon their numbers and distribution.

Additional information based on the shrub importance values (IV)(see page 396) is presented in the phytograms, Figure 8. These give a graphic representation of the relationship between the four criteria which are represented by the importance value calculation.

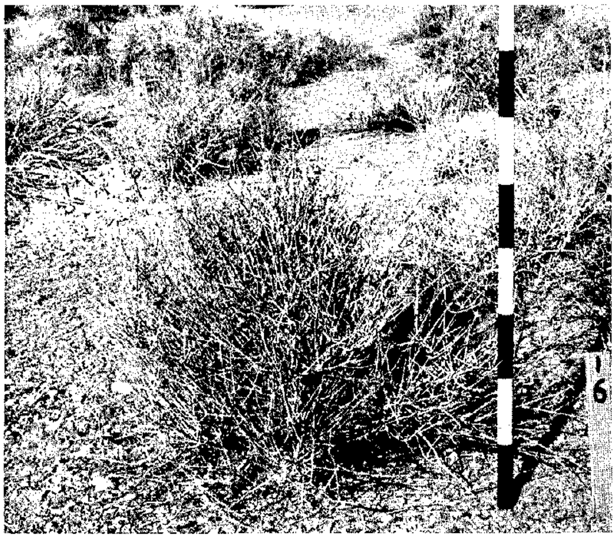


Figure 2. Ephedra nevadensis S. Wats.

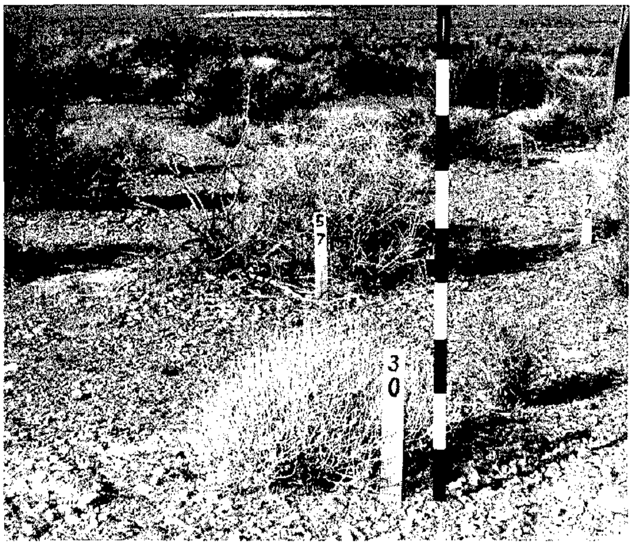


Figure 3. Franseria dumosa Gray.

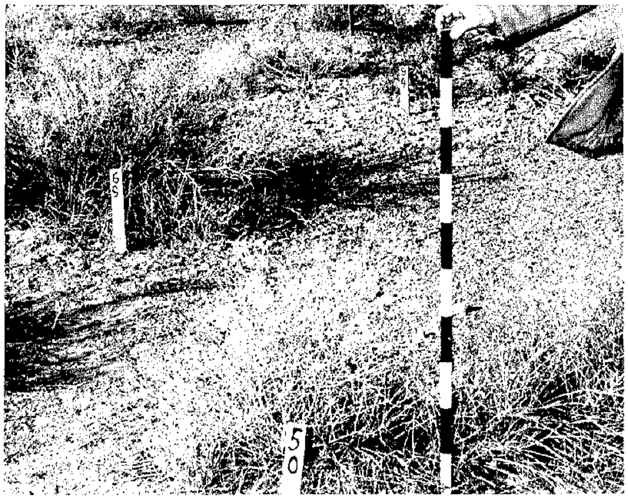


Figure 4. Grayia spinosa (Hook.) Moq.

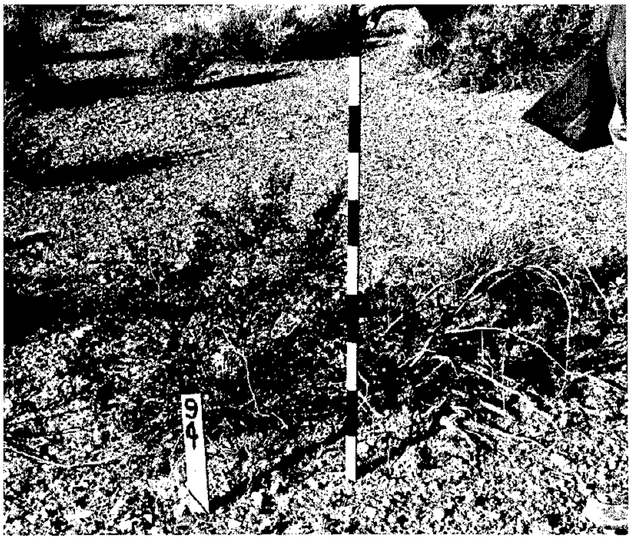


Figure 5. Larrea divaricata Cav.

Figure 6. Lycium andersonii A. Gray.

Figure 7. Lycium pallidum Miers.

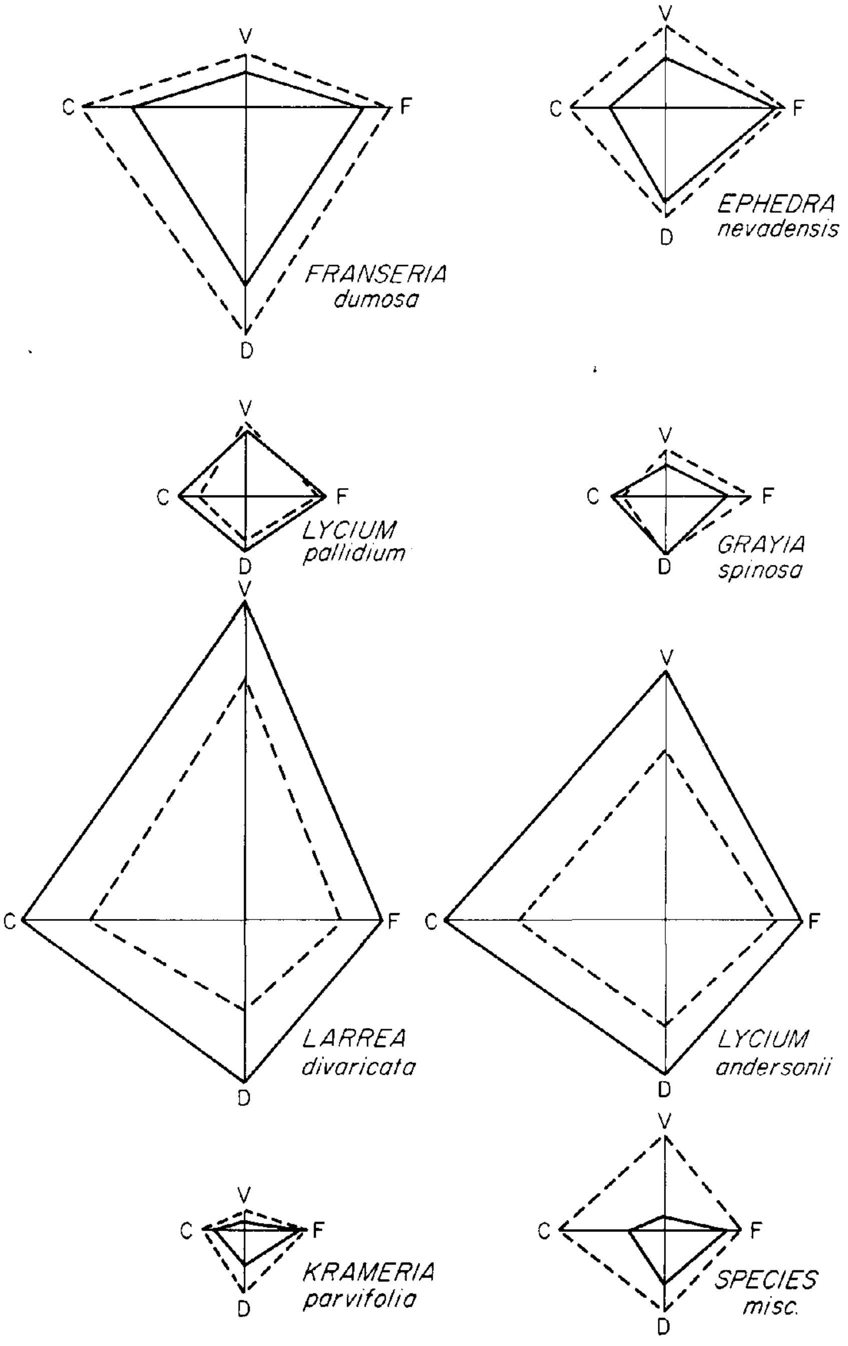


Figure 8. Phytogram of importance values for eight shrub species in the irradiated and nonirradiated plots (V, F, D, C are respectively % volume, frequency, density, and cover).

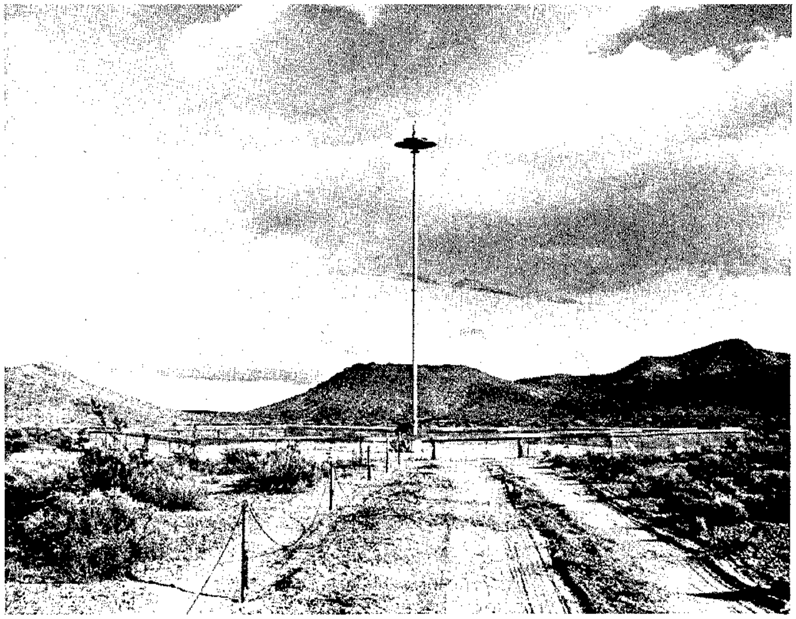


Figure 9. View of the gamma source installation in Plot B. The fence is the close-in inner fence.

Description of Facilities

In 1960 when the mammal trapping was initiated, four plots 335 m in diameter were selected. By February 1964, when this plant study began, three of these plots had been encircled with rodent-proof fences and the radiation source had been installed. Each plot had been surveyed and staked out with numbered lath into about 400, 15-meter square sub-plots. This facilitated not only the mammal trapping, but also was an aid to location for this plant study.

Because of the considerable size of the total study area, and the exacting nature of the sampling method, the plant study was confined to portions of Plot B (irradiated) and Plot D (control). The basis for this selection was discussed under Vegetation and Phenology, in this report.

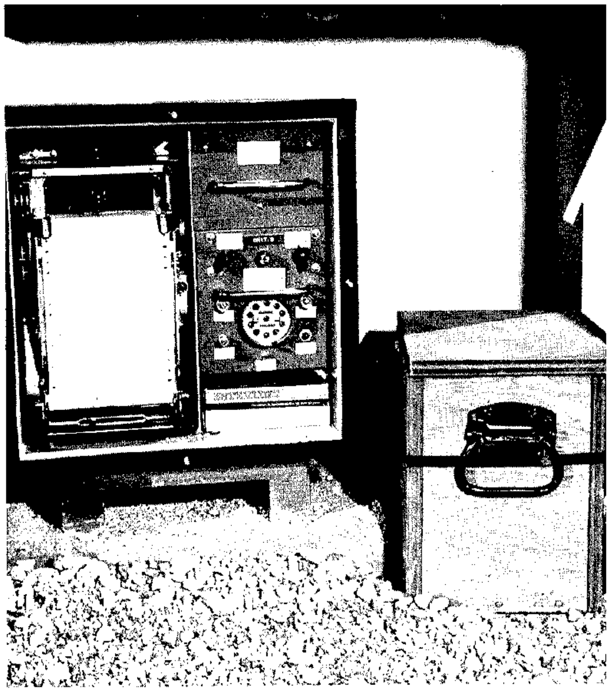
The radiation source was placed on a 15-meter tower centrally located in Plot B (see Figure 9). From a remote control station outside the radiation area, the source could be lowered into a lead shield at the base of the tower. This permitted safe access by the investigators to the study area for observation and sampling. Normally, the source was lowered into the shield for 5 days each month. For a complete discussion of the mechanical facilities and dosimetry, see French (1964).

Climatic data, vital to any study of this kind, were derived from two sources. Air Resources Laboratory installed a weather station in Rock Valley early in 1963 (see page 390). This station is centrally located between Plots C and A, providing good general coverage for the entire area. This station supplied data relative to precipitation, temperature, humidity, wind speed, and wind direction. It is the principle source of this information.

The second source of weather data is a series of stations located within each plot. Max-min recording thermometers and rain gauges were installed to provide a measure of microclimatic variability between plots.

Additional temperature data were collected with an experimental recording

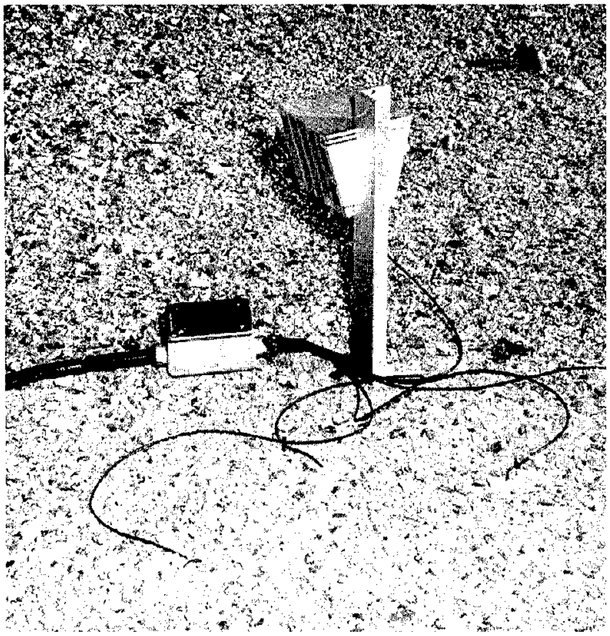
Figure 10. Field installation of the Rat Pack (Remote Area Thermograph) in the study area.



thermograph designed and constructed by the principal author (R. A. Harvey). This instrument, designated RAT PACK (Remote Area Thermograph Package), sampled ten locations of subsoil, soil surface and air temperatures in each plot consecutively and continuously. See Figures 10 and 11. The principles of design and operation of this thermograph will be reported in a subsequent paper.

In this study, there is an unfortunate and technically unavoidable deficiency in environmental assessment relative to soil moisture. Several electrical re-

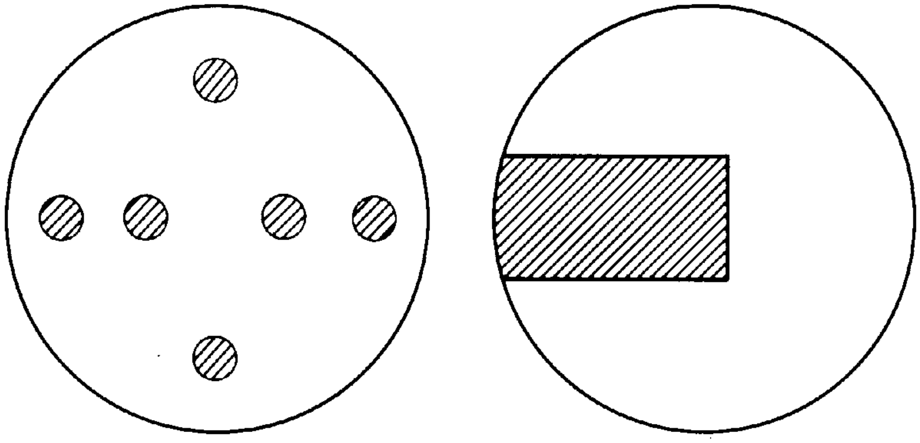
Figure 11. Soil and air temperature probes located in desert pavement.



sistance block methods were tried without any real success. The extensive dryness of the soil for long periods, high concentrations of ionic materials in the soil solution and the unsuitable structure of the soil made such methods impractical. Gravimetric sampling also proved unsuitable in an area set aside for long term studies requiring a minimum of disturbance to the environment. More recently thermocouple psychometers are being used to obtain soil moisture data.

Methodology

Methods selected to qualitatively and quantitatively assess seasonal activity and potential chronic radiation effects on plants in Rock Valley have been based upon detailed monthly observations of selected terminal shoots on the six dominant perennials. The shoots were not removed from the plants. The species were E. nevadensis, F. dumosa, G. spinosa, L. andersonii, L. pallidum, and L. divaricata. Krameria parvifolia was also examined the first year, but was deleted as it did not respond to tagging and handling.



1964 Season
Diverse sample areas

1965-67 Seasons
Zonal sample area

Figure 12. Location of tagged shrubs in Plot.

An equal number of shrubs in the irradiated and nonirradiated plots (10 plants per species per plot in 1964, 20 plants per species per plot, 1965 to 1967) were selected at random according to the patterns which appear in Figure 12. The only bias in selection was the elimination of shrubs that were obviously dead. The shrubs studied represented a range of size classes and degrees of vigor as evidenced by the community.

The shift in 1965 to rectangular rather than diverse sampling was based on two factors. First, the theoretically "equal" radiation level across the study plot had reasonable radial symmetry, but the lateral level was a gradient from about 10 R per day near the center, diminishing to about 2 R per day at the outside fence. The modified method enabled us to more effectively assess this gradient. Secondly, the more compact arrangement of the sampling proved far more efficient in terms of useful data per time invested in making observations.

The selection of shoots for detailed monthly examination required establishing rigid sampling criteria and the exercise of selective judgement. These criteria (Table 1) were selected for each species in such a manner as to minimize subjective evaluation. The same individual (R. A. Harvey) made essentially all the measurements throughout the study. This minimized inconsistencies in the data due to shifts in individual bias. All size measurements were made with vernier calipers to the nearest millimeter.

Table 1. Basis of assessment per species.

	E. nevadensis	*F. dumosa*	*G. spinosa*	*K. parvifolia*	*L. andersonii*	*L. divaricata*	*L. pallidum*
Shoot length (mm)	x	x	x	x	x	x	x
Nodes/shoot	x				x	x	x
Length/node	x				x	x	x
Leaves/shoot		x		x	x	x	x
Rosettes/shoot			x	x			
Lateral shoots/shoot	x	x	x	x	x	x	x
Lat. shoot length/shoot	x	x	x	x	x	x	x
Term. buds/shoot		x		x		x	
Lat. buds/shoot	x	x	x	x	x	x	x
Term. spines/shoot			x		x		x
Lat. spines/shoot			x		x		x
Flowers/shoot	x	x	x	x	x	x	x
Flower buds/shoot	x	x	x	x	x	x	x
Fruit/shoot	x	x	x	x	x	x	x
Surface features	x	x	x	x	x	x	x
Anomalous growth	x	x	x	x	x	x	x

The task of selecting adequate samples was quite difficult as erratic shrub growth in this area is the rule rather than the exception. An analogy which seems to appropriately apply to many of the mature shrubs is that they resemble old houses with bad plumbing. As such, the deterioration of the vascular system in older branches and root crowns gives rise to considerable variability of growth response between plants and frequently between the major branches on the same plant. The direct question, "What is *L. pallidum* doing in May of 1965?" became a statistical problem in that a direct answer would necessitate the qualification of "what *individual* shrub" or possibly "what *part* of what individual shrub." Recognizing this problem at the onset of the study, the size of the sample was made as large as could be properly handled. All samples were confined to simple terminal shoots on "active" branches. Even so, the detailed nature of assessment necessary to identify possible chronic radiation damage and restricted access to the gamma field placed definite limits upon the samples that could be examined each month. During the first season, ten shoots per shrub were tagged. In subsequent years, the number of shrubs was doubled and the shoots per shrub cut to five. Throughout the study, a total of at least 1200 shoots per season, divided equally between the irradiated and non-irradiated plots provided the basis for the data given in this report.

New shoots were selected each year during the winter dormancy to comply with the sampling criteria requiring simple terminal shoots. The tagging and sampling dates covered in this study are shown in Figure 13.

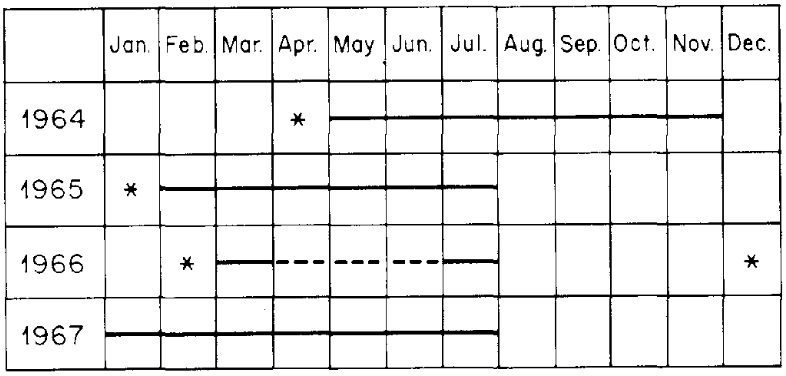


Figure 13. Time of tagging (*) and period of plant sampling (—).

Illustrations of the tagged shoots appear in Figure 14. Numbered mammal ear tags identified each shoot. Colored wires or pipe cleaners attached to the lower part of each tagged branch bearing the shoot helped to locate these tags on the shrubs. During the 1964-1965 season, shorthand diagrams of each shoot each month were used in addition to the recording of numerical data. This proved to be too time-consuming and was discontinued. The method and sample data sheets appear in Figures 15 and 16.

Additional sampling consisted of (1) monthly general phenology, (2) gross visual sampling on a monthly basis to determine the percentage of shrubs showing active growth, flowers and/or fruit, and (3) the collection of microclimatic data.

Results

Climatic Characterization

The limitations imposed upon a desert plant community by climatic factors of precipitation and temperature are generally acknowledged even though the specific mechanisms related to a given effect are not well understood. Seasonal response has been observed in this study to be abrupt. The response of the shrubs in time and in extent, is correlated with the presence of available soil moisture, soil and air temperatures above threshold values and perhaps favorable conditions of humidity and solar radiation.

From an examination of the data presented in Figures 17 to 20, a correlation can be made between moisture-temperature and seasonal response of the dominant species. The temperature calculations were made from hourly readings from a thermograph centrally located in the study area. The figures plotted represent the number of degree hours per week above $0^{\circ}C$. It appears significant that on a year to year basis these figures do not vary to any great extent. Generally, the onset of seasonal growth is correlated with a general warming from late in February to early April and begins to decline in July

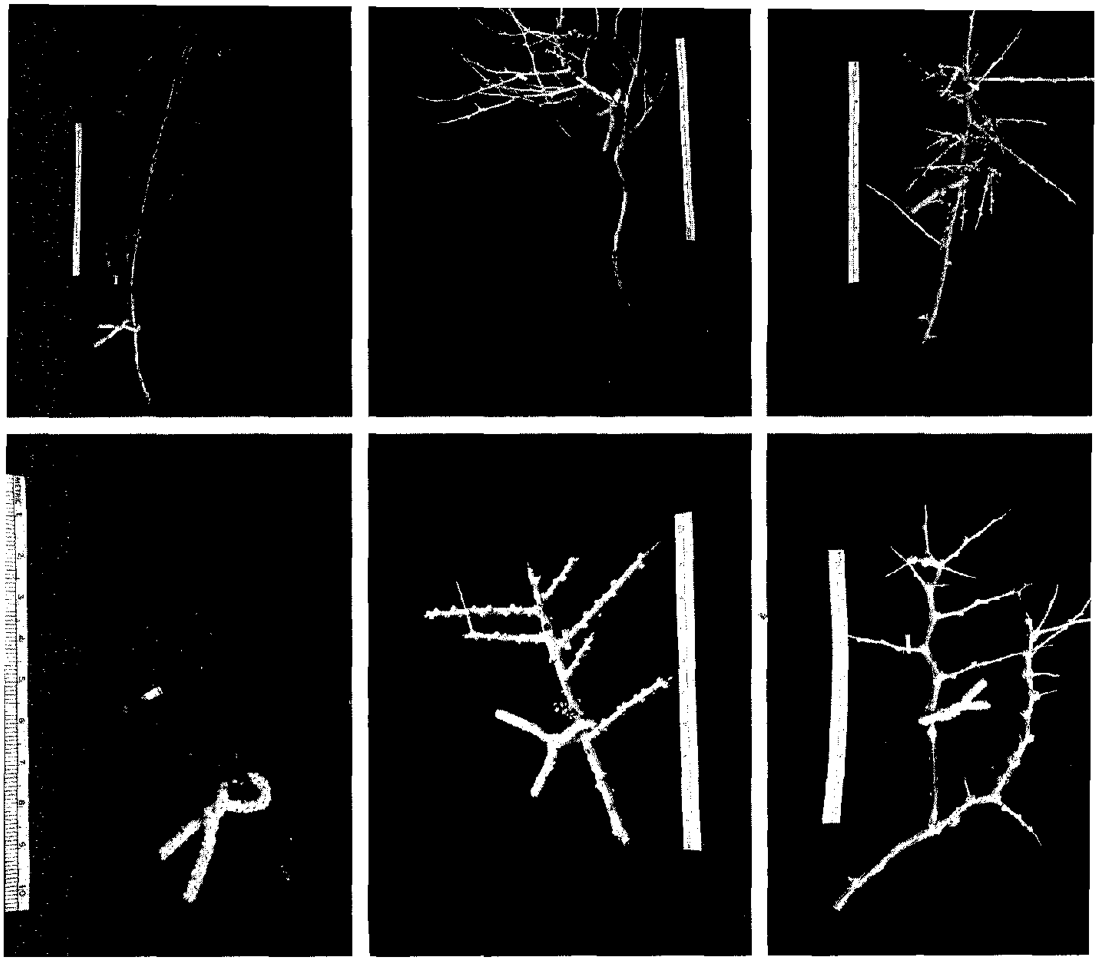


Figure 14. Tagged shoots, top left to right, E. nevadensis, F. dumosa, G. spinosa; bottom, left to right, L. divaricata, L. andersonii, and L. pallidum.

when peak temperatures occur. The occurrence of growth and its duration is more variable than temperature alone would dictate.

It seems significant that of the two factors precipitation has the greater variability. The minimal seasonal response during the 1964 season followed sub-normal precipitation of 2.5 cm from October 1963 to the first of March when the first signs of growth occurred. No substantial rainfall occurred during the spring to support the minimal growth. Conversely, the 1965 season produced abundant growth and flowering. Although winter rains to March 1965 season amounted to only 3.2 cm, a substantial rainfall of 6.0 cm which fell during April 1965 provided an adequate supply.

Early and substantial growth in 1966 is positively correlated to winter rains from October 1965 to February 1966 of 13.8 cm.

The importance of precipitation relative to the onset, duration and magnitude of seasonal growth is significant. However, precipitation should be considered from three aspects relative to its effectiveness in supplying the

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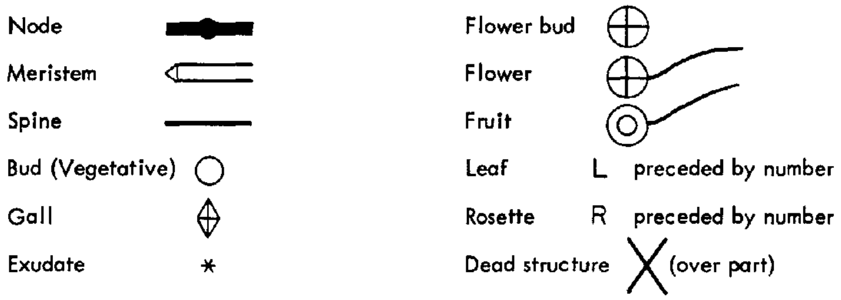
A. SYMBOL CODE



B. NUMERICAL CODE

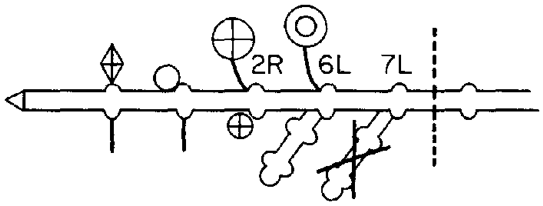
SURFACE

0 Normal
1 Dead
2 Chlorotic
3 Resinous
4 Flaccid

ANOMALOUS DEVELOPMENT

0 None
1 Mechanical damage
2 Insect gall
3 Insect damage
4 Growth deformation
5 Abortion
6 Die back

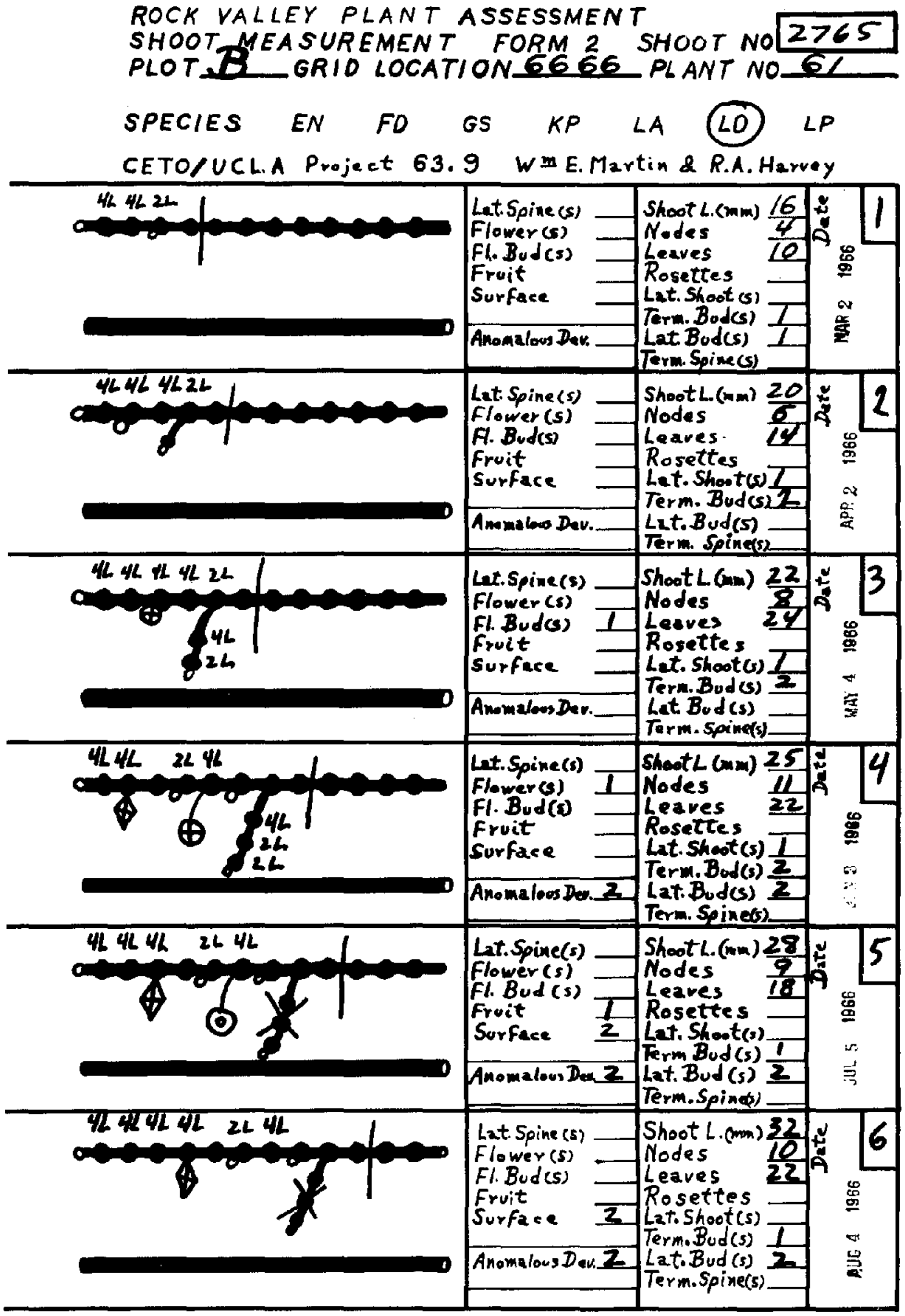
C. EXAMPLE



7 Nodes
1 Terminal meristem
2 Lateral spines
1 Gall
13 Leaves
1 Flower bud

1 Lateral bud
1 Terminal bud with exudate
1 Flower
1 Fruit
2 Lateral shoots, (one dead)
2 Rosettes

Figure 15. Shorthand method for recording plant data.



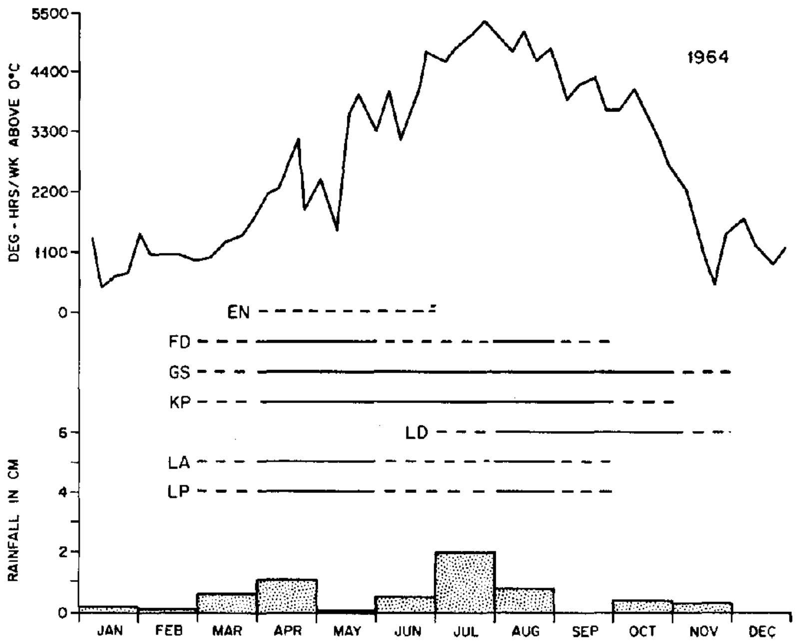
ROCK VALLEY PLANT ASSESSMENT
SHOOT MEASUREMENT FORM 2 SHOOT NO 2765
PLOT B GRID LOCATION 6666 PLANT NO 61

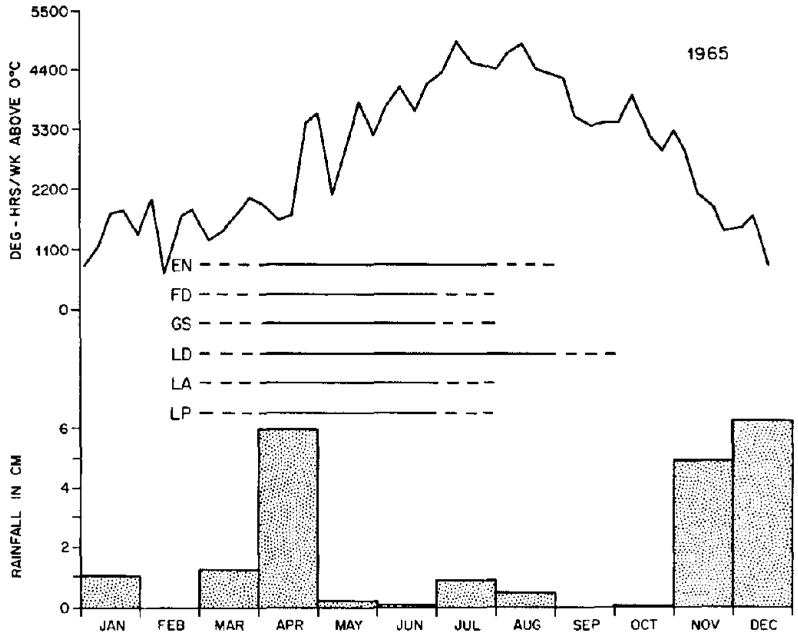
SPECIES EN FD GS KP LA [✓ LD] LP

CETO/UCLA Project 63.9 Wm E. Martin & R.A. Harvey

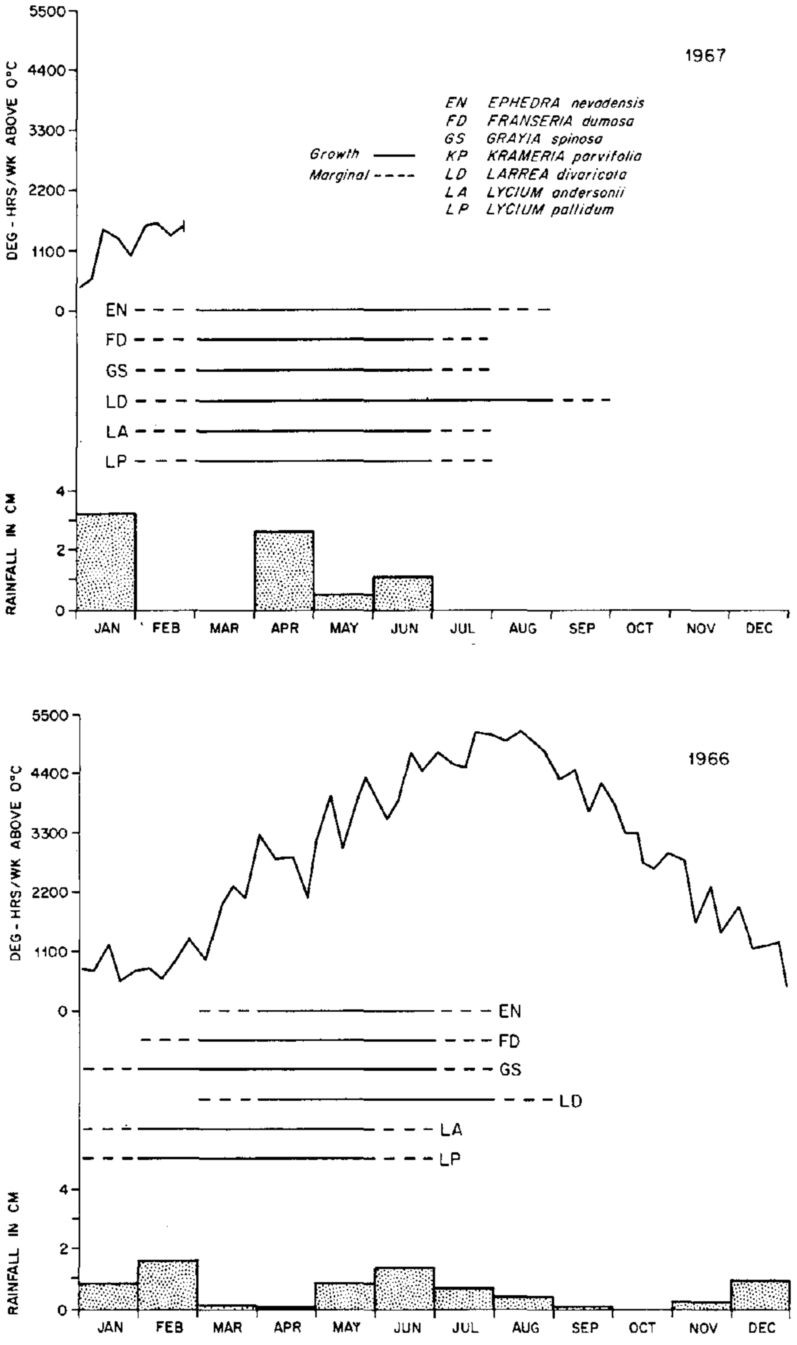
	1	2	3	4	5	6
Date	MAR 2 1966	APR 2 1966	MAY 4 1966	JUN 3 1966	JUL 5 1966	AUG 4 1966
Lat. Spine(s)						
Flower(s)				1		
Fl. Bud(s)			1			
Fruit					1	
Surface					2	2
Anomalous Dev.				2	2	2
Shoot L. (mm)	16	20	22	25	28	32
Nodes	4	6	8	11	9	10
Leaves	10	14	24	22	18	22
Rosettes						
Lat. Shoot(s)		1	1	1		
Term. Bud(s)	1	2	2	2	1	1
Lat. Bud(s)	1			2	2	2
Term. Spine(s)						

Figure 16. Sample sheet showing recorded data.





Figures 17 to 20. The phenology of major shrub species in Rock Valley area for the years 1964 to 1967 in relationship to tempera-



ture and precipitation. See figure 20 for the definitions of species abbreviations.

moisture needs of the plants. (1) The actual amount of precipitation must be sufficient to charge the soil reservoir and provide enough moisture to supply the plant when the need occurs. (2) The rate of delivery of precipitation is important in that it determines whether or not the moisture will soak into the soil, run off or evaporate. (3) The time of year when precipitation occurs bears directly on the availability of moisture to the shrubs. Summer rains lose a great deal of effectiveness because of the high temperatures and greater evaporation potential.

In terms of total annual precipitation received in the study area from March 1963 to the end of December 1966, the average was slightly below normal. Based on a 41-year record from the Beatty, Nevada Weather Station, the average precipitation is 10.5 cm. The extremes varied between 1.5 cm in 1963 to nearly 30.5 cm in 1941. It would be difficult to define what could be properly termed an "average" year relative to precipitation. This fact does identify a facet of environment that provides a significant limiting and variable factor to the plant community.

Cumulative Gamma Exposure

The radiation dose received by the plants in Plot B is contingent upon two factors: (1) the length of time the radiation source remains in the unshielded position, (2) to a lesser extent, the position of the plant in the plot relative to the distance from the radiation source.

The information in Table 2 shows the average accumulated gamma exposure received by the plants since the source was installed to the date of the measurements. Individual shoots will have accumulated exposures based upon the length of time they have been in existence in the gamma field. With few exceptions, the shoots included in this study have received the full exposure, having been present in some form since the source was installed in January 1963.

Table 2. Mean cumulative exposure of plants in Plot B to gamma radiation.

Year	Rads exposure
1964	1354
1965	2931
1966	4616
1967	6017

The degree of exposure asymmetry within the plot is shown on page 7 This reveals a variability of about 80% between those plants nearest the source and those at the outside fence.

Seasonal Response of the Dominant Shrubs

1. *Ephedra nevadensis*. With the exception of some significant production of lateral shoots on some shrubs during 1965-1967, and a scattering of flowers and fruit, the response of this species throughout the study has been minimal.

For most of the year *E. nevadensis* exists as clumps of brown and brittle, broom-like sticks. Patches of this species generally occur in close association with other shrubs in the area and these "patches" frequently have a common rootstock. In areas where erosion or excavation have cut through and exposed the roots, new plants arise from these roots. In dealing with these plants

Table 3. Some characteristics of *Ephedra nevadensis* in the nonirradiated Plot D in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	100.5	99.9	99.5	98.8	98.6	97.5	97.9
Nodes/shoot	2.6	2.6	2.6	2.5	2.5	2.5	2.3
Lat. buds/shoot	0.16						
Flowers/shoot	2.59						
Flower buds/shoot		0.16					
Fruit/shoot		0.12					
Sample size	100	97	97	96	95	95	19
Number lost		3	3	4	5	5	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	105.8	105.1	111.5	189.8	196.4	197.0
Nodes/shoot	2.8	2.7	2.8	4.7	5.0	5.1
Lat. shoots/shoot			0.80	1.24	1.22	1.17
Lat. length/shoot, mm			8.48	86.16	93.02	93.27
Flowers/shoot				1.06	0.87	0.83
Flower buds/shoot			2.71	0.29	0.16	0.10
Fruit /shoot				1.09	0.93	0.67
Sample size	100	100	99	95	94	92
Number lost			1	5	6	8

1966

	Mar.	July
Shoot length, mm	131.5	154.1
Nodes/shoot	3.0	3.5
Lat. shoots/shoot		0.54
Lat. length/shoot, mm		22.53
Sample size	100	100
Number lost		-

1967

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	83.2	84.6	91.2	102.9	129.0	144.2
Nodes/shoot	2.1	2.1	2.6	2.9	3.7	3.9
Lat. shoots/shoot			0.25	0.44	0.84	1.30
Lat. length/shoot, mm			6.96	17.83	43.29	57.83
Lat. buds/shoot		1.24	0.88	0.70	0.80	0.22
Flowers/shoot			0.05	0.18		
Flower buds/shoot			0.32	0.09		
Fruit/shoot			0.01	0.09		
Sample size	89	75	73	66	63	23

Table 4. Some characteristics of *Ephedra nevadensis* in the irradiated Plot B in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	92.2	91.1	89.7	90.0	89.7	89.5	91.3
Nodes/shoot	2.5	2.4	2.4	2.4	2.4	2.3	2.4
Lat. buds/shoot	0.02	0.23					
Flowers/shoot	0.84						
Flower buds/shoot	1.61	0.41	0.09	0.04	0.04		
Fruit/shoot		0.01					
Sample size	99	95	93	90	89	89	35
Number lost		4	6	9	10	10	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	106.6	108.6	108.7	113.7	149.8	149.6
Nodes/shoot	2.6	2.5	2.5	2.6	3.8	3.8
Lat. shoots/shoot	0.01	0.01	0.04	0.43	0.51	0.51
Lat. length/shoot, mm	0.07	0.07	0.18	7.31	44.11	44.21
Lat. buds/shoot			0.27	0.62	0.04	
Flowers/shoot			0.02	0.51		
Flower buds/shoot			1.98	0.04		
Fruit/shoot				0.04	0.04	
Sample size	100	100	95	95	92	91
Number lost		0	5	5	8	9

1966

	Mar.	July
Shoot length, mm	129.5	158.8
Nodes/shoot	3.1	4.2
Lat. shoots/shoot	0.01	0.57
Lat. length/shoot, mm	0.13	29.5
Sample size	98	98
Number lost		0

1967

	Jan.	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	125.6	127.1	127.7	129.0	131.0	175.5	221.5
Nodes/shoot	3.2	3.2	3.3	3.2	3.4	5.0	5.3
Lat. shoots/shoot				0.11	0.27	0.67	0.71
Lat. length/shoot, mm				1.52	4.26	50.60	85.33
Lat. buds/shoot		0.05	2.42	2.31	2.13	0.12	
Fruit/shoot				0.11	0.14		
Sample size	100	91	84	82	80	74	24
Number lost		9	16	18	20	26	

in the field, it is common to find that one is not dealing with a number of individuals per se but with a clone or with a common individual.

In spite of this, the species showed more variability of response than any of those examined. Shoot, flower, and fruit production in this species was very erratic. As an example, the mean lateral shoot length for a sample of 92 values for E. nevadensis in June 1965 was 44.2 mm. The standard deviation for this calculation was 10.54. Only 25.1% of the tagged shoots in Plot B at this sampling showed any lateral shoot production and one that did, having an initial length of 95 mm, had by this date produced four lateral shoots.

Flower and fruit production was equally erratic and further complicated by the fact that E. nevadensis is dioeceous and the sex of the shrub is not apparent until the flowers appear.

A summary of the data collected for this species appears in Tables 3 and 4.

2. Franseria dumosa. Although this species ranks first in D value (density) and third overall in calculated importance value (see page 396) the plant is not well adapted to the study area. The average height of 211 shrubs encountered on the intercept lines was 29.2 cm which is about 50% to 75% smaller than the same species in favorable areas. Calculations also show that an average of 16.2% of the species volume in the study area represents dead tissue.

Seasonal response of F. dumosa in the study area is largely confined to leaf production, a few lateral shoots and terminal inflorescences bearing flowers and fruit. At the onset of seasonal growth, leaves emerge from external buds along the terminal shoots. Many of these buds have remained from the previous season enclosed by dead leaves. Locating and counting these buds during dormancy is difficult without damaging the shoot. Some error does exist in this calculation during dormancy. Terminal growth does exist in the form of new leaves for a number of seasons. Like most of the other species, lateral shoot production accounts for most of the shoot elongation and the production of the inflorescences. The inflorescence consists of pistillate and staminate flowers on a catkin-like raceme. After the fruit has fallen, the raceme dies back to a short shoot which retains leaf buds and forms the basis for the next season's growth. The figures in the data relating to flowers and fruit refer to the number of infloresences bearing a number of flowers and fruit.

A summary of the data for F. dumosa appears in Tables 5 and 6.

3. Grayia spinosa. Seasonal response in this shrub takes the form of leaf and shoot production from rosettes that remain throughout dormancy. An inflorescence bearing flowers and fruit is produced on new shoots, although not all of the new shoots show this development. This species is dioecious and the data presented relative to flowers and fruit must be considered in this light. The numbers representing flowers and fruit refer to the number of inflorescences bearing many individual flowers and/or fruit.

Shoot-length increase in this species is due entirely to the elongation of new lateral shoots. This is true because the terminus of each shoot forms a stiff spine at the end of the season, losing all meristematic activity several millimeters from the apex. This factor produces a diversely branched, compact shrub. The individual shoots that form the active margin of the shrub are usually less than 50 mm in length. The new shoots bearing the inflorescence exceed this length but die back after the flowers and/or fruit have fallen. Lateral spines occur frequently along the shoots.

The main scaffold branches of this species are produced by a second form

Table 5. Some characteristics of *Franseria dumosa* in the nonirradiated Plot D in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	17.0	17.1	17.1	17.5	18.0	17.8	17.8
Leaves/shoot	7.44	4.49	1.50	10.92	5.34	1.72	3.17
Lat. shoots/shoot		0.03	0.04	0.06	0.14	0.12	0.11
Lat. length/shoot, mm		0.11	0.14	0.31	0.78	0.66	0.56
Term. buds/shoot	0.97	1.02	1.04	1.06	0.82	0.75	1.06
Lat. buds/shoot	0.27	2.13	1.64	3.00	1.94	1.83	1.55
Sample size	99	96	96	95	94	93	18
Number lost		3	3	4	5	6	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	19.2	19.2	19.6	42.9	58.9	57.7
Leaves/shoot			0.16	5.28	5.00	2.70
Lat. shoots/shoot	0.04	0.04	0.09	0.57	1.51	0.58
Lat. length/shoot, mm	0.18	0.18	0.52	22.83	38.58	37.46
Term. buds/shoot	0.96	0.96	0.81	0.84	0.86	0.85
Lat. buds/shoot	3.45	3.44	3.72	2.47	3.34	2.53
Flowers/shoot				0.49	0.31	0.02
Flower buds/shoot						0.01
Fruit/shoot					0.27	0.16
Sample size	100	100	100	98	96	96
Number lost				2	4	4

1966

	Mar.	July
Shoot length, mm	49.5	110.7
Lat. shoots/shoot		1.30
Lat. length/shoot, mm		60.30
Sample size	100	100
Number lost		

1967

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	46.2	46.9	52.5	75.6	95.7	83.7
Leaves/shoot		4.93	8.44	20.13	14.00	7.80
Lat. shoots/shoot		0.01	0.29	0.77	0.89	0.93
Lat. length/shoot, mm		0.10	5.12	25.03	43.84	37.87
Term. buds/shoot			0.28	0.28	0.24	0.20
Lat. buds/shoot	1.13	1.04	0.30	0.38	0.27	1.20
Flowers/shoot				0.03		
Flower buds/shoot			0.02	0.49		
Fruit/shoot					0.38	
Sample size	93	89	82	39	37	15
Number lost						

Table 6. Some characteristics of *Franseria dumosa* in the irradiated Plot B in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	18.4	18.4	18.7	19.2	19.0	18.8	18.9
Leaves/shoot	4.30	2.95	0.99	7.21	3.06	1.24	1.55
Term. buds/shoot	0.91	0.96	0.75	0.94	0.81	0.77	0.74
Lat. buds/shoot	0.63	2.16	1.46	2.18	1.53	1.38	1.06
Sample size	100	98	93	90	85	85	31
Number lost		2	7	10	15	15	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	16.6	16.6	16.6	24.5	35.7	34.5
Leaves/shoot				3.00	3.25	1.91
Lat. shoots/shoot				0.30	0.30	0.31
Lat. length/shoot, mm				7.89	18.80	17.60
Term. buds/shoot	0.95	0.95	0.82	0.94	0.89	0.88
Lat. buds/shoot	2.63	2.63	2.95	2.44	2.11	1.94
Flowers/shoot				0.10	0.02	
Fruit/shoot					0.17	0.04
Sample size	100	100	100	98	92	91
Number lost				2	8	9

1966

	Mar.	July
Shoot length, mm	78.0	147.1
Lat. shoots/shoot		1.18
Lat. length/shoot, mm		68.55
Sample size	100	100
Number lost		

1967

	Mar.	Apr.	May	June	July
Shoot length, mm	46.7	58.3	65.1	77.9	89.2
Leaves/shoot	9.63	20.27	22.5	11.71	3.23
Lat. shoots/shoot		0.69	0.72	0.89	1.0
Lat. length/shoot, mm		9.83	15.90	28.10	41.77
Term. buds/shoot		0.67	0.43		
Lat. buds/shoot	0.86	1.11	0.42	0.02	0.08
Flowers/shoot				0.12	
Flower buds/shoot		0.03	0.25		
Fruit/shoot				0.23	
Sample size	98	63	60	56	13
Number lost					

Table 7. Some characteristics of Grayia spinosa in the nonirradiated Plot D in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	27.5	27.4	27.5	28.2	28.4	28.6	30.4
Leaves/shoot	0.04						
Rosettes/shoot	4.29	3.94	3.75	4.37	3.42	2.94	2.82
Lat. shoots/shoot		0.05	0.08	0.23	0.23	0.31	0.29
Lat. length/shoot, mm		0.21	0.28	0.81	0.91	1.12	1.12
Lat. buds/shoot	0.08	0.85	0.66	0.40	0.87	1.31	0.76
Flowers/shoot		0.01					
Sample size	99	97	97	93	92	90	17
Number lost		2	2	6	7	9	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	28.1	28.2	30.2	51.3	51.9	51.9
Leaves/shoot			3.61	11.51	10.33	4.38
Rosettes/shoot	2.75	2.71	2.12	0.96	0.96	3.48
Lat. shoots/shoot			0.29	1.23	1.28	1.28
Lat. length/shoot, mm			1.97	23.11	24.10	24.10
Term. buds/shoot			0.22	0.14	0.11	0.03
Lat. buds/shoot	1.47	1.49	1.44	0.79	0.72	0.72
Flowers/shoot				0.39	0.03	0.02
Fruit/shoot				0.67	0.71	0.27
Sample size	100	100	100	100	97	97
Number lost					4	4

1966

	Mar.	July
Shoot length, mm	36.0	89.0
Rosettes/shoot		10.99
Lat. shoots/shoot	0.02	2.07
Lat. length/shoot, mm	0.23	53.22
Sample size	100	99

1967

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	28.7	30.8	34.74	36.81	35.90	36.4
Leaves/shoot			6.54	18.26	9.09	1.18
Rosettes/shoot	4.00	3.84	2.41	3.71	4.04	3.14
Lat. shoots/shoot		0.25	0.41	0.51	0.49	0.36
Lat. length/shoot, mm		2.07	6.31	7.73	6.88	5.32
Term. buds/shoot		0.05	0.21	0.22		
Lat. buds/shoot		0.06	0.03	0.01		
Flowers/shoot			0.17			
Fruit/shoot			0.04	0.12		
Sample size	97	95	95	78	77	28
Number lost		2	2	19	20	

Table 8. Some characteristics of Grayia spinosa in the irradiated Plot B in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	32.6	32.6	33.1	33.6	33.6	33.7	33.1
Leaves/shoot		0.01			0.06		
Rosettes/shoot	5.05	5.06	5.02	5.06	4.76	4.70	4.52
Lat. buds/shoot	0.19	0.35	0.26	0.30	0.13	0.62	0.55
Sample size	100	97	91	80	72	71	31
Number lost		3	9	20	28	29	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	30.6	30.6	30.8	50.1	50.6	49.4
Leaves/shoot			0.07	11.47	10.45	4.38
Rosettes/shoot	1.94	1.94	1.82	0.59	0.72	3.40
Lat. shoots/shoot			0.03	1.24	1.30	1.29
Lat. length/shoot, mm			0.13	19.51	19.93	18.71
Term. buds/shoot			0.01			
Lat. buds/shoot	1.82	1.82	1.54	0.86	0.71	0.68
Flowers/shoot				0.85	0.01	
Flower buds/shoot				0.01	0.01	
Fruit/shoot				0.53	0.63	0.05
Sample size	100	100	97	96	94	94
Number lost			3	4	6	6

1966

	Mar.	July
Shoot length, mm	37.0	100.9
Rosettes/shoot	0.09	11.52
Lat. shoots/shoot		1.79
Lat. length/shoot, mm		63.95
Sample size	99	99

1967

	Jan.	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	46.0	46.3	62.0	87.7	86.2	83.2	84.90
Leaves/shoot				34.17	32.27	19.52	4.29
Rosettes/shoot	5.44	5.46	5.92	0.24	8.54	8.98	8.29
Lat. shoots/shoot			1.44	1.75	1.76	1.69	1.43
Lat. length/shoot, mm			15.36	41.45	39.96	36.98	40.19
Term. buds/shoot			0.41	0.08	0.03		
Flowers/shoot				1.04	0.04		
Flower buds/shoot			1.02				
Fruit/shoot				0.14	0.26		
Sample size	98	97	95	93	92	90	21
Number lost		1	3	5	6	8	

of shoot growth. During years that are particularly favorable for vegetative growth, a dozen or more exceptionally vigorous shoots arise either from the root crown or from places along the lower parts of major branches. Between March and June of 1966, for example, many of these "volunteers" grew in excess of 60 cm in addition to numerous accessory shoots. In some plants, this increased the shrub volume by as much as 20% based on estimates of biomass.

It is safe to say that during "average" years, seasonal response in *G. spinosa* takes the form of short lateral shoot production together with some flowers and fruit, leaves arising from rosettes of buds at the nodes and infrequently new short lateral spines.

During "exception" years, new scaffold branches are rapidly produced. These replace those older branches that have either died back during poor years or were damaged by some physical means.

A summary of the data collected for *G. spinosa* appears in Tables 7 and 8.

4. *Krameria parvifolia*. This species was eliminated from the sampling after the first season as it did not respond to tagging and handling. The shoots were very fragile and could not bear the weight of the tags. The summary data for 1964 appears in Tables 9 and 10.

Table 9. Some characteristics of *Krameria parvifolia* in the nonirradiated Plot D in Rock Valley.

	1964						
Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	22.0	22.3	22.9	28.4	34.8	35.0	21.0
Leaves/shoot	7.95	7.16	5.39	9.00	5.32	3.36	1.25
Rosettes/shoot						0.64	
Lat. shoots/shoot		0.01	0.01	0.26	0.34	0.36	0.25
Lat. length/shoot, mm		0.04	0.04	3.77	8.05	7.92	1.50
Term. buds/shoot				0.02	0.16	0.33	
Lat. buds/shoot		0.06	0.38	2.70	2.97	2.92	2.50
Flower buds/shoot				0.05	0.05		
Sample size	100	97	85	57	38	36	4

Table 10. Some characteristics of *Krameria parvifolia* in the irradiated Plot B in Rock Valley.

	1964						
Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	25.9	28.0	27.4	33.1	43.1	50.0	46.8
Leaves/shoot	8.84	9.14	6.75	10.16	9.28	6.88	6.85
Rosettes/shoot						0.17	0.05
Lat. shoots/shoot		0.08	0.06	0.31	0.58	0.79	0.80
Lat. length/shoot, mm		0.33	0.24	4.57	12.23	16.98	12.45
Term. buds/shoot				0.07	0.25	0.67	0.75
Lat. buds/shoot				1.64	1.84	3.19	2.90
Sample size	91	84	83	67	57	42	20

5. Larrea divaricata. A summary of the data obtained for L. divaricata is in Tables 11 and 12. Seasonal response in this evergreen shrub is characterized by more subtle changes than those that abruptly produce full leaf and flower cover within a few days during the spring season. Paired, divaricate, sessile, asymmetrical leaflets are produced at prominent nodes on the terminal shoots. The leaves, buds, and soft stems are covered with a strong-scented resinous exudate. The condition of active growth or dormancy is easily determined by measuring the terminal shoot length, recognizing new nodes as they are produced, observing axillary bud and lateral shoot development, and assessing the presence of flowers and/or fruit on these shoots.

It appears from the monthly observations of this shrub throughout the year that vegetative growth proceeds any time that climatic and edaphic conditions are favorable. It also appears that the rate of growth and the total growth for the season is determined by the amount of available moisture and soil and air temperatures.

During the dormant periods, particularly during the hot dry months, this species becomes brittle, yellow, and loses some of the older leaves. The terminal leaves which remain on the plant become flaccid. Some moisture is absorbed by these leaves from light showers that do not effectively charge the soil. On several occasions during the study, this species showed some greening after light showers, but no apparent growth.

During the principal growing season, this species showed great variability of response. This was true not only between individual plants, but even various parts of the same plant. Some shrubs, for example, consisting of from 10 to 20 branches from the root crown had all of the obvious growth confined to several branches while the others showed little or no response. During the study we were not able to predict which branches on our sample shrubs would respond and which would not respond. This variability appeared to reflect to some extent, branch age, deterioration of root and stem vascular tissues due to weathering, insects, etc. Variable depths of soil and differences in drainage patterns across the study areas also contributed to this variability.

6. Lycium andersonii. A summary of the data obtained for L. andersonii is in Tables 13 and 14. This spiny, deciduous shrub is considerably branched and devoid of leaves for most of the year in the study area. The onset of seasonal growth is abrupt in the appearance of numerous spatulate leaves and pale lavender flowers which emerge from prominent, calloused nodes on the terminal shoots. Lateral shoots began to emerge in an asymmetrical fashion from some of the nodes. As each of these shoots ends in a terminal spine, there is no elongation of these shoots in subsequent seasons. Leaves and flowers, and occasionally lateral shoots, emerge from the nodes even on older stems.

Great variability exists between individual shrubs and even parts of the same shrub. Like L. divaricata this species shows numerous branches which emerge from a root crown. With age and injury some branches fail to produce any more than a few leaves and an occasional flower. In a large percentage of the individual shrubs in the study area nearly all of the stem growth is confined to a few branches on the plant.

Criteria selected on this species for assessing seasonal growth was largely confined to the production of leaves, flowers and fruit. A few tagged shoots also produced a limited number of lateral shoots and these were also measured and evaluated.

7. Lycium pallidum. A summary of the data obtained for L. pallidum is

Table 11. Some characteristics of *Larrea divaricata* in the nonirradiated Plot D in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	12.7	13.6	13.9	21.8	23.8	33.7	24.4
Nodes/shoot	3.38	3.83	3.96	6.16	6.63	6.76	6.50
Leaves/shoot	10.75	12.17	11.35	19.84	18.80	15.80	15.06
Lat. shoots/shoot		0.12	0.20	1.00	1.11	1.08	1.25
Lat. length/shoot, mm		0.23	0.40	4.30	5.07	5.36	4.75
Term. buds/shoot	1.00	1.11	1.18	1.98	2.07	2.00	2.25
Lat. buds/shoot	0.39	0.40	0.38	0.20	0.24	0.27	0.19
Sample size	100	99	95	92	89	88	16
Number lost		1	5	8	11	12	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	12.0	12.0	15.4	28.1	35.9	38.9
Nodes/shoot	2.76	2.76	3.45	5.73	7.04	7.63
Leaves/shoot	8.82	8.77	10.77	19.40	23.63	22.45
Lat. shoots/shoot			0.15	1.03	1.47	1.55
Lat. length/shoot, mm			0.56	5.91	10.14	11.60
Term. buds/shoot	1.00	1.00	1.05	1.97	2.35	2.46
Lat. buds/shoot	0.02	0.02	0.39	0.23	0.20	0.17
Sample size	100	100	99	99	79*	92
Number lost			1	1		8

1966

	Mar.	July
Shoot length, mm	25.7	42.4
Nodes/shoot	4.79	8.70
Leaves/shoot	15.56	22.88
Lat. shoots/shoot	1.51	1.63
Lat. length/shoot, mm	4.53	15.04
Term. buds/shoot	1.59	2.36
Lat. buds/shoot	0.62	0.51
Sample size	97	83
Number lost		14

1967

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	14.6	16.6	21.6	27.1	34.8	31.8
Nodes/shoot	3.00	3.30	4.55	5.58	7.28	7.30
Leaves/shoot	8.38	9.30	13.80	17.39	22.89	19.75
Lat. shoots/shoot	0.02	0.06	0.35	0.76	1.09	1.00
Lat. length/shoot, mm	0.10	0.32	1.97	4.96	9.14	8.10
Term. buds/shoot	0.98	1.05	1.34	1.69	1.89	1.95
Lat. buds/shoot	0.20	0.29	0.48	0.30	0.17	
Sample size	97	94	92	90	88	20
Number lost	3	6	8	10	12	

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*Malfunction of program.

Table 12. Some characteristics of *Larrea divaricata* in the irradiated Plot B in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	10.5	10.9	10.9	16.0	17.2	18.0	20.5
Nodes/shoot	2.68	2.93	2.96	4.62	4.88	4.75	5.10
Leaves/shoot	9.28	9.53	8.77	13.85	13.49	11.99	12.60
Lat. shoots/shoot		0.08	0.09	0.55	0.63	0.56	0.77
Lat. length/shoot, mm		0.24	0.19	1.75	1.99	2.23	3.27
Term. buds/shoot	0.99	1.05	1.08	1.47	1.45	1.43	1.53
Lat. buds/shoot	0.34	0.26	0.22	0.36	0.49	0.25	0.23
Sample size	100	96	93	91	89	77	30
Number lost		4	7	9	11	23	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	12.5	12.6	13.6	26.1	38.0	41.7
Nodes/shoot	2.92	2.93	3.16	5.36	7.41	8.12
Leaves/shoot	8.89	8.88	8.28	16.80	24.48	24.03
Lat. shoots/shoot	0.01	0.01	0.14	0.88	1.41	1.62
Lat. length/shoot, mm	0.04	0.04	0.18	5.12	11.78	14.32
Term. buds/shoot	1.01	1.01	1.00	1.78	2.30	2.43
Lat. buds/shoot	0.08	0.08	0.16	0.34	0.28	0.26
Sample size	100	100	100	98	97	94
Number lost				2	3	6

1966

	Mar.	July
Shoot length, mm	23.9	38.3
Nodes/shoot	4.96	7.64
Leaves/shoot	15.67	21.70
Lat. shoots/shoot	0.65	1.47
Lat. length/shoot, mm	4.01	12.43
Term. buds/shoot	1.63	1.71
Lat. buds/shoot	0.48	0.58
Sample size	99	90
Number lost		9

1967

	Jan.	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	15.3	15.8	16.9	21.2	25.8	31.0	35.1
Nodes/shoot	3.40	3.48	3.64	4.84	5.99	7.15	8.17
Leaves/shoot	6.62	7.31	7.72	11.83	14.91	18.31	19.88
Lat. shoots/shoot			0.08	0.48	0.79	0.89	1.13
Lat. length/shoot, mm			0.36	2.15	4.72	6.98	8.71
Term. buds/shoot	0.99	0.98	1.02	1.42	1.69	1.79	1.83
Lat. buds/shoot	0.26	0.29	0.26	0.39	0.27	0.37	0.17
Sample size	97	50(?)	96	98	97	91	24
Number lost		?	1	0	0	6	

Table 13. Some characteristics of *Lycium andersonii* in the nonirradiated Plot D in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	21.5	21.5	21.6	21.6	21.5	21.5	21.9
Nodes/shoot	8.54	8.54	8.59	8.60	8.61	8.61	9.06
Leaves/shoot	12.79	2.16	0.09	9.07	0.81		
Lat. buds/shoot	0.35			0.11			
Fruit/shoot	0.05	0.01					
Samples size	100	98	94	94	93	92	17
Number lost		2	6	6	7	8	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	32.0	32.0	32.8	35.1	35.1	35.3
Nodes/shoot	9.38	9.32	9.38	9.38	9.35	9.41
Leaves/shoot			27.43	28.56	25.48	0.41
Lat. shoots/shoot			0.06	0.07	0.06	0.07
Lat. length/shoot, mm			0.76	3.11	3.09	3.16
Term. buds/shoot			0.05	0.01		
Flowers/shoot				0.41		
Flower buds/shoot			2.86	0.07	0.03	
Fruit/shoot				1.66	1.39	
Sample size	100	99	100	100	101	99

1966

	Mar.	July
Shoot length, mm	34.7	54.1
Nodes/shoot	11.88	18.14
Lat. shoots/shoot		0.59
Lat. length/shoot, mm		19.37
Sample size	100	100

1967

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	40.4	40.7	42.3	43.0	43.1	41.0
Nodes/shoot	11.89	11.89	12.00	12.07	12.07	11.13
Leaves/shoot	0.27	24.14	21.45	21.78	13.29	0.04
Lat. shoots/shoot		0.03	0.05	0.05	0.05	0.04
Lat. length/shoot, mm		0.22	1.54	1.94	1.97	0.92
Term. buds/shoot		0.03	0.04			
Lat. buds/shoot	0.38	0.58	0.20	0.56		
Flowers/shoot			0.15	0.01		
Flower buds/shoot		0.05	0.15			
Fruit/shoot				0.13		
Sample size	100	100	97	89	89	24
Number lost			3	11	11	

Table 14. Some characteristics of Lycium andersonii in the irradiated Plot B in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	20.8	20.7	20.8	20.7	20.8	20.8	20.7
Nodes/shoot	7.17	7.16	7.13	7.29	7.36	7.37	7.27
Leaves/shoot	12.31	1.70	0.09	6.85	1.30		
Lat. buds/shoot	0.06		0.03	0.18	0.01		
Flowers/shoot	0.02						
Fruit/shoot	0.14	0.02					
Sample size	99	99	91	87	83	83	44
Number lost			8	12	16	17	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	29.3	29.3	29.4	29.9	30.1	30.1
Nodes/shoot	9.18	9.18	9.22	9.22	9.22	9.11
Leaves/shoot	0.23	0.23	25.12	28.29	22.59	
Lat. shoots/shoot				0.02	0.02	0.02
Lat. length/shoot, mm				0.57	0.62	0.62
Term. buds/shoot				0.01		
Lat. buds/shoot			0.15	0.12	0.12	0.12
Flowers/shoot			0.02	3.83	0.03	
Flower buds/shoot			0.91	0.35	0.02	
Fruit/shoot	0.04	0.04	0.06	0.40	1.44	0.28
Sample size	100	100	99	99	99	98
Number lost			1	1	1	2

1966

	Mar.	July
Shoot length, mm	33.6	40.2
Nodes/shoot	8.73	10.07
Lat. shoots/shoot		0.15
Lat. length/shoot, mm		6.54
Sample size	100	100

1967

	Jan.	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	36.8	37.0	36.8	39.8	39.7	39.8	41.6
Nodes/shoot	8.43	8.45	8.28	9.16	9.20	8.58	9.67
Leaves/shoot		0.11	18.73	17.13	15.07	9.67	
Lat. shoots/shoot	0.01	0.01	0.05	0.17	0.17	0.17	0.25
Lat. length/shoot, mm	0.06	0.06	0.55	3.21	3.23	3.24	3.96
Term. buds/shoot			0.06	0.13	0.04		
Lat. buds/shoot		1.07	0.48		0.53	0.08	
Flowers/shoot				0.46			
Flower buds/shoot			0.07	0.17			
Fruit/shoot					0.27	0.02	
Sample size	100	100	95	95	92	92	24
Number lost			5	5	8	8	

in Tables 15 and 16. This species is very similar in form and seasonal response to L. andersonii. It is distinguished by its brown, rather than grey bark on the older wood, and its large leaves, flowers and fruit.

Sampling criteria used for L. andersonii also applied to this species.

Tentative Levels Required for Gross Effects of Radiation.

1. Supportive data from a portable ^{60}Co unshielded gamma source.

The problem of recognizing and quantitating subtle, marginal radiation effects in a plant community already under stress from natural causes is a formidable task. We soon recognized the desirability of establishing some guidelines relative to the dose levels necessary to produce measurable effects and to the characterization of the manner in which this damage would be revealed.

In August 1964 we obtained a 1200 curie ^{60}Co gamma source and a portable delivery system. This material was furnished by the Radiological Science Division of the Reynolds Electrical and Engineering Company at the Nevada Test Site. The equipment consisted of a heavily shielded source container mounted on a trailer. By remote control, a hydraulic system attached to the container permitted the delivery of the ^{60}Co pellet to a stationary "catcher" in the field through a plastic tube. Recovery of the ^{60}Co pellet at the end of the exposure is accomplished by reversing the hydraulic flow in the delivery tube, returning it to the shielded container on the trailer. For a thorough description of this Multi-Purpose Irradiator (MPI-1) see Lund and McKnight (1963).

The plant irradiation experiment (PIE#1) which we conducted with this equipment provided us with valuable data on radiation effects on L. divaricata, L. andersonii, and C. ramosissima. A second experiment (PIE#2) in another area provided similar data for E. nevadensis and G. spinosa (Rhoads et al., 1969).

As a result of the PIE#1 study, three classes of radiation damage were established. It is significant to note that these classes of damage were not immediately apparent in all cases, some requiring a year or more to fully develop. The parameters of damage for each class increased with time, revealing seriously damaged plants that initially appeared to be marginal. In the case of all species involved in the PIE#2 study, no decisive damage was apparent for at least 10 months even though the dose level exceeded 100,000 R to plants nearest the gamma source.

The classes of damage based on the PIE#1 study are:

Class I: Characterized by
  a. The total loss of leaves.
  b. The total destruction of terminal and lateral buds.
  c. Gross to total loss of terminal shoots and small stems.
  d. Remaining wood brittle and in some cases showing deposits of exudate. These plants are obviously dead, although new root crown sprouts may appear at a later time.

Class II: Characterized by
  a. Gross to complete cessation of terminal growth.
  b. Obvious chlorosis and significant leaf loss.
  c. Shrunken and discolored buds which remain permanently inactive or result in erratic and anomalous growth.
  d. Gross to complete absence of flower buds in season.
  e. Initial wilt response in some plants.

Table 15. Some characteristics of *Lycium pallidum* in the nonirradiated Plot D in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	34.2	34.2	34.2	34.4	34.4	34.6	35.5
Nodes/shoot	5.94	6.01	6.00	6.07	6.07	6.08	6.31
Leaves/shoot	12.78	1.07		0.58	0.11		
Lat. shoots/shoot				0.03	0.03	0.04	0.03
Lat. length/shoot, mm				0.23	0.23	0.29	0.18
Lat. buds/shoot	0.08	0.01	0.01	0.02	0.04	0.01	
Sample size	100	99	99	99	99	98	49
Number lost		1	1	1	1	2	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	38.7	38.7	38.7	39.4	39.5	39.6
Nodes/shoot	4.80	4.80	4.80	4.73	4.73	4.73
Leaves/shoot			18.44	16.51	14.70	0.18
Lat. shoots/shoot				0.02	0.02	0.02
Lat. length/shoot, mm				0.89	0.88	0.87
Term. buds/shoot				0.02	0.02	0.01
Lat. buds/shoot			0.04	0.04	0.04	0.40
Flowers/shoot				0.21		
Flower buds/shoot			0.67			
Fruit/shoot			0.01	0.45	0.26	0.14
Sample size	100	100	100	98	99	100
Number lost				2	1	

1966

	Mar.	July
Shoot length, mm	35.1	38.5
Nodes/shoot	4.92	5.53
Lat. shoots/shoot	0.07	0.21
Lat. length/shoot, mm	1.03	4.48
Sample size	100	100
Number lost		

1967

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	36.6	37.7	37.6	38.0	37.9	42.8
Nodes/shoot	5.72	5.93	5.89	6.12	6.01	8.05
Leaves/shoot		16.21	14.91	16.61	11.19	5.71
Lat. shoots/shoot			0.01	0.01	0.01	
Lat. length/shoot, mm			0.13	0.14	0.11	
Term. buds/shoot			0.01	0.01		
Lat. buds/shoot		0.68	0.29	0.09	0.13	0.29
Flowers/shoot			0.01			
Flower buds/shoot		0.07				
Sample size	89	81	80	74	72	21
Number lost		8	9	15	17	

Table 16. Some characteristics of Lycium pallidum in the irradiated Plot B in Rock Valley.

1964

Measurement	May	June	July	Aug.	Sept.	Oct.	Nov.
Shoot length, mm	40.1	40.1	40.5	40.5	40.5	40.8	46.2
Nodes/shoot	5.93	5.93	5.91	5.91	5.94	5.92	6.49
Leaves/shoot	17.23	0.89	0.06	0.07			
Lat. shoots/shoot	0.01	0.01	0.03	0.03	0.03	0.03	0.08
Lat. length/shoot, mm	0.14	0.14	0.36	0.37	0.38	0.39	0.95
Lat. buds/shoot	0.04			0.01			
Sample size	100	100	96	95	97	95	39
Number lost			4	5	3	5	

1965

	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	52.1	52.1	51.9	52.6	52.8	52.9
Nodes/shoot	6.38	6.38	6.41	6.29	6.31	6.32
Leaves/shoot			19.32	26.13	20.74	1.13
Lat. shoots/shoot				0.03	0.05	0.04
Lat. length/shoot, mm				0.66	0.79	0.68
Lat. buds/shoot			0.84			
Flowers/shoot	0.01	0.01	0.01	0.87	0.03	0.01
Flower buds/shoot			0.12	0.18	0.02	
Fruit/shoot				0.24	0.29	0.02
Sample size	100	100	100	95	94	93
Number lost				5	6	7

1966

	Mar.	July
Shoot length, mm	33.8	41.3
Nodes/shoot	4.69	5.44
Lat. shoots/shoot		0.32
Lat. length/shoot, mm		7.55
Sample size	98	98
Number lost		

1967

	Jan.	Feb.	Mar.	Apr.	May	June	July
Shoot length, mm	29.2	30.8	31.7	31.7	32.8	31.3	29.1
Nodes/shoot	4.36	4.36	4.83	4.83	5.13	4.72	4.39
Leaves/shoot	0.05	0.06	14.59	13.23	16.30	6.43	1.22
Lat. shoots/shoot						0.02	0.06
Lat. length/shoot, mm						0.08	0.28
Lat. buds/shoot		0.20	0.26	0.04	0.47	0.14	0.06
Flowers/shoot				0.01			
Flower buds/shoot			0.22				
Fruit/shoot				0.12			
Sample size	100	79	69	69	65	65	18
Number lost		21	31	31	35	35	

f. Beads of resinous exudate on buds in L. divaricata

Class III: Characterized by
- a. Marginal conditions of Class II.
- b. Reduction of flowering as the most obvious effect.
- c. Some reduction in shoot elongation and lateral shoot initiation.

An additional Class IV could be added with more exacting means of assessment including cytological observations. It is important to remember that a range of radiation effects do occur between what is actual and what is apparent. We are dealing not with an all or none phenomenon, but with a continuum of effect. Classification of damage is, therefore, arbitrary and subject to certain practical limitations.

The data presented in Table 17 show the approximate exposure levels required on the species studied to produce the classes of damage which have been described. These figures represent acute doses, therefore, they may not represent the chronic levels necessary to produce the same degree of effect. Higher chronic levels are probably necessary to produce an equivalent effect. Direct comparisons between chronic and acute doses are difficult to make when the plants studied are so profoundly affected by the season and climate. Different responses to acute radiation can be expected from the irradiation of dormant or active plants. This aspect of the study needs amplification.

Table 17. Observed gamma exposures showing ultimate classes of damage on four species.

Species	Class I	Class II	Class III
Ephedra nevadensis	>5,000 R	5,000-600 R	600-200 R
Grayia spinosa	>100,000 R	100,000-17,000 R	<17,000 R
Larrea divaricata	>30,000 R	30,000-8,000 R	8,000-4,500 R
Lycium andersonii	>20,000 R	20,000-7,800 R	7,800-5,000 R

It is, we believe, reasonable to predict that the data from PIE#1 and PIE#2 have a direct bearing upon the Rock Valley study. Any chronic effect can be expected to first show itself as Class III damage. This should take the form of reduced shoot elongation, reduction of lateral shoot production, and perhaps a reduction in flower, fruit, and leaf development.

2. Possible early gross effects in Rock Valley.

A multivariate analysis of all the data obtained in this study (Table 18) was prepared and reported by French (1969). See also page 6 and the report of Kaaz et al. (1971). The results suggested that the three plant species with the highest estimated nuclear volume had some differences between plots. Whether or not the differences were due to radiation could not be ascertained from the data with surety so the study reported on page 5 was undertaken. In any event the species with suggested differences between plots were those having the highest nuclear volumes as one would suspect (Sparrow et al., 1961, 1962, 1963, 1965, 1966, 1968, 1969). In the new study made in 1969 only the E. nevadensis had differences which could be attributed to radiation. One of the difficulties of the approach made in the study reported here was the time between sampling periods. It was apparent that phenological events could happen and be missed by sampling periods which were one month apart.

This study has led to the development of sampling techniques which are

Table 18. Multivariate analysis of Rock Valley shrub growth.

Species	Estimated nuclear vol., μ^3	Among years	Between plots	Interaction
Ephedra nevadensis	600-800	F = 13.93**	F = 3.39**	F = 4.56**
Franseria dumosa	152	F = 42.94**	F = 1.24 NS	F = 7.26**
Grayia spinosa	128	F = 32.48**	F = 1.70 NS	F = 1.56 NS
Larrea divaricata	212	F = 18.43**	F = 8.46**	F = 5.78**
Lycium andersonii	466	F = 41.81**	F = 3.84**	F = 7.16**
Lycium pallidum	176	F = 15.41**	F = 0.49 NS	F = 1.09 NS
Degrees of freedom for F		12 & 1251	4 & 453	12 & 1251

NS = Not significant * = Significant 5% level ** = Significant 1% level

useful in the study of seasonal changes in desert shrubs. The techniques indicated that radiation of 2 to 10 R per day after a 7-year period may just be beginning to have some effect on flowering and/or fruiting responses of some of the shrubs. Shrub species having high nuclear volumes seemed to have increased susceptibility to radiation. More studies in this area will be made in future years.

Summary

A study to assess the effects of low intensity chronic irradiation on desert shrubs was conducted in Rock Valley adjacent to the Nevada Test Site, Nye County, Nevada. From February 1964 to September 1967 a careful record was kept concerning the qualitative and quantitative responses of six dominant species in an irradiated and a control plot. The data reported here represent over one-half million observations of tagged terminal shoots on these shrubs. Although definite radiation effects on these species were inconclusive at the time when the study was concluded, valuable information relative to seasonal dynamics in these plants is presented. Supplemental to this, specific data are presented relative to desert community composition and the climatic and edaphic profiles which characterize the area.

SOME EFFECTS OF GAMMA RADIATION ON SEED GERMINATION AND SEEDLING SURVIVAL

The recovery of an ecosystem that has been partially destroyed by nuclear events will depend partly upon the effect of ionizing radiation on seeds. Many studies have been made of effects of ionizing radiation on seeds (Heaslip, 1959; Johnstone and Klepinger, 1967; Micke, 1966; Vig, 1969). Many of these studies indicate that radiation effects on plants are related to the target size, i.e., to the cellular nuclear volume (Baetcke et al., 1967; Sparrow, 1966; Sparrow et al., 1961, 1963, 1967, 1968; Sparrow and Miksche, 1961; Sparrow and Pugielli, 1969; Sparrow and Sparrow, 1965; Yamakawa and Sparrow, 1965, 1966; Woodwell and Sparrow, 1965). Micke (1966) reported that the radiosensitivity of seeds was also related to such secondary factors as moisture contents from seeds and oxygen content of the moisture. Johnstone and Klepinger (1967) reported that roots of Yucca brevifolia seedlings for seeds irradiated before germination were more sensitive to the irradiation than were the shoots. Heaslip (1959) found a great amount of variation among 18 deciduous tree species on radiation effects and also found that sensitivity to radiation was increased after seed dormancy was broken. Vig (1969) found that irradiation with a ^{60}Co source of Cyamopsis tetragonaloba at an exposure of 5 to 30 kR speeded up germination and increased the rate of root growth. Several other nongenetic changes were involved.

The purpose of the present series of studies was to determine some effects of gamma radiation on germination characteristics for a number of desert plants in an effort to predict long-time ecosystem changes which might be occasioned by some types of nuclear events.

Experimental Results

Seeds of the species studied were collected from the Nevada Test Site. They were exposed in test tubes to the 10,000 curie ^{60}Co source at UCLA at various levels of irradiation which had been arrived at by preliminary experiments. The number of seeds in each tube ranged up to 100 and was related to the availability of seed. After irradiation the seeds were planted either in vermiculite or in Yolo loam soil in flats maintained in the glasshouse. Routine care was given them and germination counts and measurements made of them at appropriate time intervals. Species involved included Artemisia tridentata, Salsola pestifera, Yucca schidigera, Larrea divaricata, Atriplex canescens, Franseria dumosa, Yucca brevifolia, Lycium andersonii, and Lycium pallidum.

Data for irradiation of A. tridentata are in Table 1. Germination was little affected by the radiation levels which were up to 25 kR. After 18 days, however, some seedlings at 20 and 25 kR started to die and at 50 days nearly all at those two levels had failed to survive. LD_{50-50} was about 15 kR.

Data for S. pestifera are in Table 2. Germination was slightly decreased at 200 kR but after 12 days and continuing to 48 days survival gradually decreased for all levels of irradiation. LD_{50-48} was about 100 kR. As mentioned on page 149 very high levels (around 1 million R) are needed to stop germination in this species but cells elongate only at high levels of irradiation; they do not divide.

Data are in Table 3 for Y. schidigera, L. divaricata, and A. canescens. Above 20 kR no germination was evident for Y. schidigera but dead root sys-

Table 1. Effect of gamma radiation of 100 *A. tridentata* seeds on germination and survival characteristics when grown in vermiculite after seeds had been irradiated (100 seeds per lot).

Level of irradiation	No. of plants germinating or remaining alive for different time periods.						
	Days						
kR	4	8	12	18	28	36	50
0	11	22	25	24	21	22	17
5	9	32	32	33	28	23	14
10	18	32	33	32	30	27	21
15	13	32	33	32	30	24	11
20	7	22	22	19	13	10	3
25	15	25	26	23	8	5	2

Table 2. Effect of gamma radiation on lots of 50 *S. pestifera* seeds on subsequent germination and survival after irradiated seeds were planted in vermiculite.

Level of irradiation	Days after planting						
	4	8	12	18	22	28	48
kR	No. of seed germinated or surviving						
0	28	29	24	30	28	25	29
25	13	21	16	19	18	17	18
50	17	24	22	23	22	19	12
75	28	37	28	- - - - - - - lost - - - - - -			
100	28	36	34	32	27	20	15
150	19	23	19	23	18	11	5
200	19	15	13	16	16	11	5
250	19	14	11	10	12	5	0

Table 3. Effect of gamma radiation on germination characteristics of *Y. schidigera*, *L. divaricata*, and *A. canescens* seeds germinated in Yolo loam soil after irradiation.

	Y. schidigera (30 seeds) after 22 days		*L. divaricata* (40 seeds) after 37 days		*A. canescens* (50 seeds) after 23 days
Level of irradiation	dry wt/ seedling	germination	dry wt/ seedling	germination	germination
kR	g	%	g	%	%
0	0.0781	67	0.0338	35	2
10	0.0689	60	0.0294	45	6
20	0.0620	54	0.0241	42	6
40	0.0128	3	0.0473	45	2
60	0.0070*	0	0.0433	8	0
100	0.0087*	0	—	0	4

* Roots but no tops.

Table 4. Effect of gamma radiation of seeds on germination characteristics of *F. dumosa* and *Y. brevifolia* grown in vermiculite.

Level of irradiation	% germinated or surviving after, days			Dry wt/plant after 120 days		Top/ root
kR	10	20	120	Top	Root	Ratio
			F. dumosa (25 seeds per lot)			
0	8	12	20	0.16	0.02	8.0
10	8	16	8	0.85	0.10	8.5
20	28	28	4	0.04	0.01	4.0
40	32	32	24	0.27	0.04	7.8
60	40	48	24	0.16	0.03	7.1
			Y. brevifolia (35 seeds per lot)			
0	3	92	94	0.082	0.031	2.62
10	23	92	92	0.079	0.025	3.22
20	6	97	100	0.097	0.035	2.77
40	0	86	83	0.050	0.023	2.13
60	0	51	57	0.041	0.020	2.10

tems without shoots were found present for the plants at 40, 60, 100 kR when removed from the soil for harvest after 22 days. LD$_{50-22}$ was about 30 kR. No *L. divaricata* germinated for the 100 kR level and only 8% at the 60 kR level. The dry weights of those at 60 kR, however, were as large or even larger than those of the controls. LD$_{50-37}$ was about 50 kR. *A. canescens* germinated poorly and did not seem to be related to the radiation exposure.

Data for irradiation of *F. dumosa* and *Y. brevifolia* are in Table 4. *F. dumosa* germination was not decreased by levels used. *Y. brevifolia* was not affected by levels below 80 kR and showed somewhat more resistance than that reported by Johnstone and Klepinger (1967). LD$_{50-120}$ was over 60 kR.

Table 5. Effect of radiation on germination characteristics of *L. andersonii*, *L. pallidum*, *A. canescens*, and *F. dumosa* grown in vermiculite. (25 seeds per lot)

	L. andersonii	*L. pallidum*	*A. canescens*	*F. dumosa*
kR	% germination (67 days)			
0	0	4	4	24
10	4	8	4	28
20	8	0	8	24
40	16	12	8	20
	Condition of seedlings (G is good; S is small)			
0	-	G	G	G
10	G	G	G	G
20	G	-	G	G
40	S	S	S	G

Table 6. Nuclear volume data for some of the species used.*

Species	Chromosome counts From literature	BNL*	μ^3 Nuc. vol.	μ^3 ICV	kR where changes in germination occurred
A. tridentata	2n = 18, 36	Probably 36 medium	487	13.5?	15
A. canescens	x = 9	? small	198	—	150
F. dumosa	In other species of *Franseria* 2n = 36, 72	Probably 36 small	152	4.2?	150
L. divaricata	x = 13 2n = 26, 52, 104	? very small	212	—	40
L. andersonii	x = 12	Probably 48 small	466	9.7?	20
S. pestifera	2n = 36	36	176	4.9	75
Y. schidigera	x = 30	60 bimodal 10 large, 50 very small	292	4.9	20

*All data except germination data in this table are courtesy of Mrs. Anne Rogers and Dr. Arnold Sparrow, Brookhaven National Laboratory (BNL).

Another seed irradiation test was made involving L. andersonii, L. pallidum, A. canescens, and F. dumosa. Twenty-five seeds of each were irradiated at 0, 10 kR (5.2 minutes), 20 kR (10.4 minutes), and 40 kR (20.8 minutes) in test tubes. The seeds were then planted in vermiculite in the glasshouse and germination observed. The greatest difficulty in the study was low percentage germination. A summary of the numbers of germination is given in Table 5.

The sensitivity of the seeds of the various species was very much related to their nuclear volume or to the interphase chromosome volume (Table 6). The hypothesis of Sparrow et al. (1961, 1963, 1967, 1968) concerning the target size of the nucleus or of the interphase chromosome volume seems to hold in the present data.

The relatively high exposure levels necessary to cause significant changes in seed germination and in seedling survival would suggest that past nuclear testing (see page 54) at the Nevada Test Site would result in relatively little effect of radiation on germination of seeds and seedling survival in the area. Indirect effects are something else.

Summary

Seeds of several species of desert plants were irradiated with a ^{60}Co gamma source at various exposures and characteristics of germination and seedling survival were recorded. In general the radiation had a greater effect on seedling survival than on germination. The sensitivity of the species to the radiation was greatly related to nuclear volume. Few Artemisia tridentata seedlings survived for radiation levels above 15 kR and for Yucca schidigera, above 20 kR. Larrea divaricata was little affected by levels up to 40 kR while Atriplex canescens, Franseria dumosa, Yucca brevifolia, and Salsola pestifera were much more resistant to the radiation.

RADIATION DAMAGE ON NATURAL VEGETATION IN CLOSE-IN FALLOUT AREAS

Summary Statement

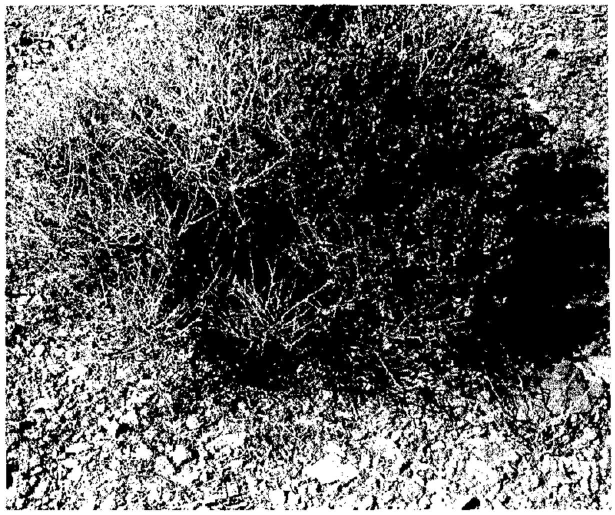
The first decade of nuclear testing at the Nevada Test Site primarily involved above-ground detonations of tower and balloon-mounted devices. The nature of these detonations was such that most of the natural vegetation near ground zero was destroyed by fire and blast effects rather than by ionizing radiation. For the most part, those materials which were converted to atmospheric fallout were drawn upward from the ground-zero site with the ascending fireball and subsequently dispersed from the fallout cloud formed at high altitudes. The levels of radiation in the fallout debris ultimately deposited downwind from these above-ground detonations generally were not sufficient to damage natural vegetation.

The second decade of testing primarily involved underground detonations of nuclear devices which, upon venting, sometimes resulted in radiation damage to vegetation in close-in fallout areas. Radiation levels in fallout debris deposited from Plowshare nuclear excavation tests also were sufficiently high to damage vegetation in discrete fallout patterns extending several km downwind from the craters. Notable examples were the Sedan (1962), Palanquin (1965), Cabriolet (1968) and Schooner (1968) events. Martin (1963), Beatley (1965), Rhoads et al. (1969a, and b, 1970) have described damage to vegetation in these close-in fallout areas. Included herein is a summary of some gross radiation effects on vegetation which were observed in the fallout patterns of Palanquin, Cabriolet, and Schooner at sites not damaged by heat, blast or throw-out materials. The history, experimental work, and results from collaborative program efforts at these sites are described in detail by Rhoads et al. (1969, 1970). This summary is a brief review of the effects.

1. Where fallout radiation levels were sufficiently high, complete defoliation and kill of natural vegetation occurred as illustrated in Figure 1. Damage primarily was caused by beta radiation from fallout debris deposited upon vegetation. Romney et al. (1963) described the nature of fallout particle retention

Figure 1. Beta radiation from fallout debris deposited upon and retained by plant foliage primarily causes the damage and destruction of natural vegetation in close-in fallout areas.

Figure 2. Beta radiation in fallout debris deposited upon and retained by foliage destroyed the top and side of this Atriplex confertifolia shrub facing toward ground zero. Partially sheltered foliage on the leeward side of the shrub was damaged but not destroyed.



by plant foliage. Mixed grasses and winter and summer annuals, especially the Salsola species, began to reappear in these areas during the year after fallout occurred. The damage from fallout radiation was not immediately visible. In fact, the symptoms involved in ultimate death of trees and shrubs generally developed during a period of 3 to 6 months. The first visible symptom was a slight yellowing of foliage. In the Artemisia shrubs this was usually followed by suppression or failure of inflorescence development. The Juniperus osteosperma trees failed to develop their characteristic small, blue-grey fruit. The chlorosis pattern on plant foliage continued to become increasingly severe until all leaves abscised and death occurred. Damaged grasses developed new growth from natural crown sprouting, as did the Ephedra species.

2. In areas of fallout patterns peripheral to where all or most plants were killed, the radiation damage to shrubs was often manifested in a particular fashion which depended upon the manner in which fallout debris was deposited upon and retained by the plant foliage. More damage often occurred on the

Figure 3. A "skirting" effect caused by defoliation of the underside of an Artemisia tridentata shrub by high levels of beta radiation from fallout debris deposited on the ground as particles too large to adhere onto the foliage.

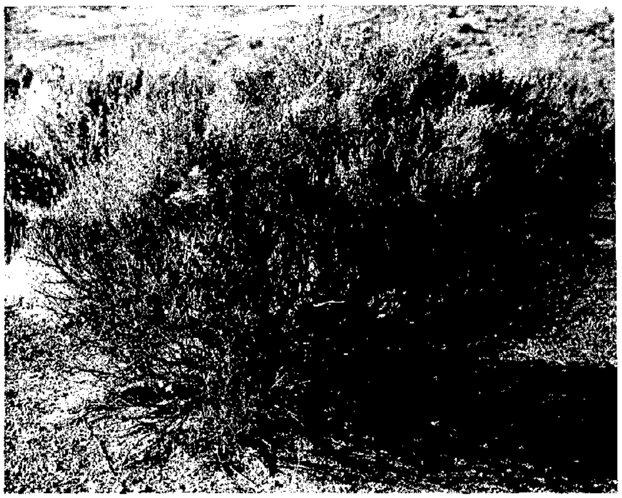


Figure 4. Sheets of 6 mil polyethylene plastic were placed on plots of natural vegetation for protection from beta radiation in fallout debris. The protection afforded is good evidence that beta radiation was the cause of injury to surrounding plants. Soil was placed on the edge of the cover to anchor it. Covers remained in place during and for 2 weeks after fallout deposition.

sides of shrubs facing toward ground zero than on the leeward sides. This asymmetrical damage was caused by beta radiation from fallout particles differentially deposited around the shrub. An example of this effect is shown in Figure 2 which illustrates how the side of an Atriplex confertifolia shrub facing ground zero was asymmetrically destroyed by the beta radiation in very fine fallout debris moving across the landscape. Figure 3 illustrates the "skirting" effect commonly observed in the close-in Schooner fallout pattern which was caused by defoliation of the underside of Artemisia tridentata shrubs by high levels of beta radiation from fallout debris deposited on the ground as particles too large to adhere onto the foliage.

Both beta and gamma radiation contributed to the damage of vegetation in close-in fallout areas inasmuch as their effects were additive. However, be-

Figure 5. Plots of natural vegetation protected with 6-mil thick plastic covers during and for 2 weeks after fallout was deposited survived beta-kill. Photograph was taken 15 months after fallout occurred.

cause of its inherent nature, beta radiation contributed the most damage when fallout debris was deposited upon and retained by plant foliage. This effect was strikingly demonstrated in the Schooner fallout patterns wherein plots of natural vegetation were protected from fallout debris during and for two weeks after fallout deposition. Figure 4 illustrates how sheets of 6 mil thick polyethylene plastic were fixed in place by shoveling soil completely around the edges in order to anchor them firmly to the ground. At sites where fallout radiation completely destroyed the unprotected vegetation, that which was protected from fallout debris by plastic covers was undamaged as illustrated in Figure 5. The natural vegetation in these plots not only survived destruction by protection from beta radiation in fallout debris but it also responded afterward to the additional soil moisture made available as the result of surrounding vegetation having been destroyed by radiation.

PERSISTENCE OF RADIONUCLIDES IN SOIL, PLANTS, AND SMALL MAMMALS IN FALLOUT CONTAMINATED AREAS

Introduction

The distribution and characteristics of fallout debris from above-ground nuclear tests were studied intensively by research teams from UCLA during the decade after nuclear weapons testing began at the Nevada Test Site in 1951. The biotic availability of fallout radionuclides, especially the long-lived ^{90}Sr and ^{137}Cs fission products, also was investigated during this period at several permanent sampling sites established in fallout patterns at various distances downwind from the nuclear detonations. Results from some of these early studies have been reported (Larson et al., 1952, 1962, 1966; Olafson et al., 1953; Rainey et al., 1954; Lindberg et al., 1954, 1959; Lindberg and Larson, 1956; Baurmash et al., 1958, Larson, 1959; French and Larson, 1961; Neel and Larson, 1963; Romney et al., 1963, Hawthorne, 1965).

During the next decade, beginning with the Sedan event in 1962, studies were continued to investigate biotic availability of radionuclides and radiation effects on biota in close-in fallout areas downwind from Plowshare nuclear excavation tests. Some results from these studies also have been reported (Martin, 1963, 1964, 1965 a and b; Turner, 1963, 1965; Beatley, 1965; Essington et al., 1965; Turner and Gist, 1965; Martin and Turner, 1966; Romney et al., 1966; Romney and Rhoads, 1966; Turner and Jennrich, 1966; Rhoads et al., 1969 a and b, 1970).

Reported herein are findings on the persistence of radionuclides in biota living in the old fallout areas originally contaminated by debris from above-ground nuclear weapons tests and in some close-in fallout areas more recently contaminated by debris from nuclear excavation tests.

Materials and Methods

The location of the old fallout study sites relative to the Nevada Test Site is illustrated in Figure 1. These sites originally were established on the mid-line of highest irradiation intensity in well defined fallout patterns resulting from nuclear detonations during the Upshot/Knothole (1953), Teapot (1955), and Plumbbob (1957) test series. Inasmuch as fallout from successive tests cross-contaminated these study sites, one cannot relate the residual radionuclide contamination to a given fallout event. Nevertheless, these sites still serve for evaluating radionuclide persistence in native biota in spite of the shortcoming of cross-contamination and sparse radiological surveillance in recent years. The levels of radionuclides in soils were determined each time biotic surveys were made. Additional study sites were established in close-in fallout patterns from nuclear excavation tests which occurred in the Yucca Flat and Pahute Mesa test areas of the Nevada Test Site. Included were the Sedan (1962), Palanquin (U20K, 1965), Cabriolet (1968), and Schooner (1968) test events. Recent work has been focused in the U20K fallout pattern.

Methods of collecting, processing, and radiochemical analysis of samples have been reported (Lindberg et al., 1954, 1959; Larson et al., 1966). Briefly, soil samples were taken at 0-2.5 cm depth for radiochemical assay and for use in plant uptake tests under glasshouse conditions. Rabbit samples (*Lepus* spp. and *Sylvilagus* spp.) were collected with .22 cal. rifle and kangaroo rats (*Dipodomys* spp.) were trapped on grid lines which originally transected the

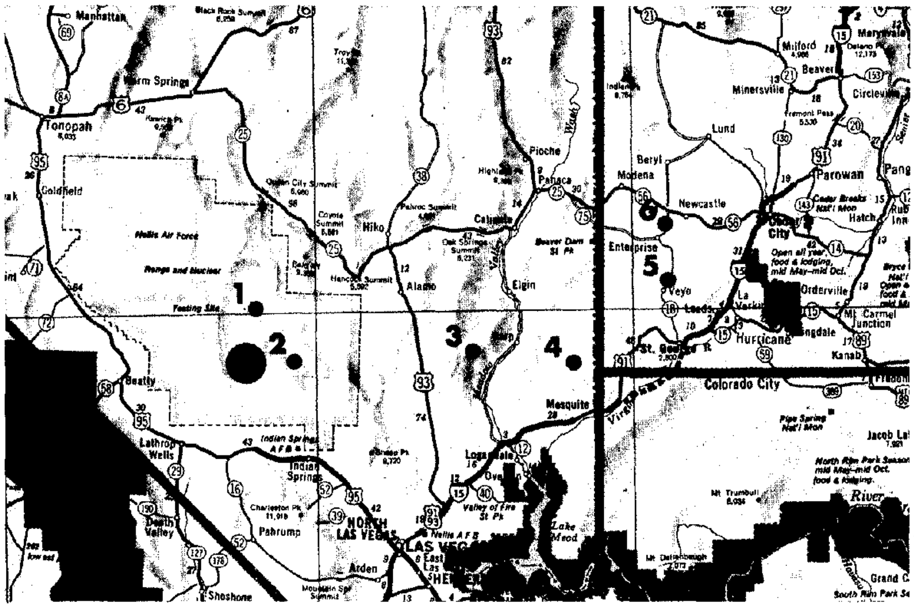


Figure 1. Location of fallout persistence study sites in southern Nevada and Utah in relation to the Nevada Test Site.

mid-line of highest fallout intensity. All animal specimens were stored in dry ice until processed for radiochemical analysis. Individual rabbits were processed separately; kangaroo rats were pooled together and processed in lots varying from 10 to 20 specimens per sample. They were separated into bone, muscle, gastrointestinal tract and contents, and lung fractions for determining radionuclide concentrations. Gamma spectrometric assays were made on soil, plant, and animal samples, and ^{90}Sr, ^{137}Cs, and ^{144}Ce contents were determined by beta assay of samples chemically separated.

Glasshouse pot tests were run to determine the extent of ^{90}Sr and ^{137}Cs uptake through roots from soil collected from the fallout study sites. Samples were thoroughly mixed and potted in 10 kg lots. Some were treated with EDDHA and DTPA chelating agents at the level of 100 ppm dry weight. Alfalfa (Medicago sativa L. 'Ranger') was grown on these soils during the first year of the test; Franseria dumosa Gray, a common native desert shrub, was grown during the second year.

Results and Discussion

Results from the 1966 survey of the old fallout persistence sites are shown in Table 1. Both ^{90}Sr and ^{137}Cs continued to move through the gastrointestinal tracts of jackrabbits and kangaroo rats sampled. There were only trace amounts or non-detectable levels of these two radionuclides in lung tissue; therefore, it appears that the importance of inhalation has decreased while ingestion has increased as the route of radionuclide entry into small mammals with passing time. A similar trend was detected in ^{239}Pu-contaminated fallout areas (Rom-

Table 1. Relative concentrations of ^{90}Sr and ^{137}Cs in samples of soil, plants and small mammals collected in 1966 from old fallout areas.

Site	km from G. Z.*	Isotope	Soil[a]	Plant[b]	Jackrabbit (*Lepus* spp.)[c]			Kangaroo rat (*Dipodomys* spp.)[d]		
					Bone	Muscle	G I tract	Bone	Muscle	G I tract
			Disintegrations/min./g dry weight							
1	22	^{90}Sr	8.2	1.7	14.4	2.4	10.7	12.2	3.1	8.3
		^{137}Cs	7.4	1.3	-	10.0	12.6	-	10.9	19.8
2	26	^{90}Sr	26.8	2.6	7.2	1.1	6.5	7.5	2.8	6.7
		^{137}Cs	15.4	3.7	-	13.5	13.7	-	22.4	17.3
3	109	^{90}Sr	9.6	1.1	10.5	0.7	6.4	7.5	1.8	3.9
		^{137}Cs	6.6	1.2	-	18.0	15.6	-	12.5	12.3
4	160	^{90}Sr	5.3	2.3	17.4	1.0	10.1	8.2	1.7	5.9
		^{137}Cs	7.1	1.9	-	24.0	37.1	-	6.1	12.0
5	216	^{90}Sr	2.8	-	10.9	-	2.6	9.2	-	2.4
		^{137}Cs	3.8	-	-	1.8	3.9	-	4.8	9.7
6	224	^{90}Sr	2.5	-	9.8	-	6.5	7.2	-	4.2
		^{137}Cs	4.2	-	-	9.1	6.9	-	4.1	5.4

*G. Z. = ground zero.

[a] 2.5 cm surface soil; [b] mixed grass spp.; [c] mean of 2 to 9 replicates; [d] pooled samples of 12 to 20 kangaroo rats.

ney et al., 1970). The ^{90}Sr accumulated in bone and ^{137}Cs accumulated in muscle tissue. During the early period after fallout occurred, it was found that ^{90}Sr and ^{137}Cs were more available to biota at greater distance from ground zero (Lindberg et al., 1954, 1959; Romney et al., 1963). This was attributed to greater solubility of the smaller sized fallout particles deposited further downwind from the nuclear detonation. There continued to be some indication of this in 1966, particularly for ^{90}Sr in bone tissue. At no time have we detected gross anatomic lesions while processing animal samples. It seems apparent that small amounts of ^{90}Sr and ^{137}Cs will continue to move from abiotic components in these old fallout areas with passing time.

Results from studies in the close-in fallout area of a nuclear excavation test appear in Table 2. Data are shown on the relative concentrations of ^{90}Sr ^{137}Cs, and ^{144}Ce in samples of soil, plants, and small mammals collected in 1966 and 1967 at sampling sites in the Palanquin (U20K) fallout pattern. Note the greater importance of inhalation as an entry route of radionuclides into small mammals during the early period after fallout occurred in 1965. At the time of this writing (1971), inhalation has decreased while ingestion has increased in importance as the route of radionuclide entry into small mammals living in the fallout area. Gamma spectrometric results (Figures 2 and 3) showed that a number of other radionuclides, including neutron activation products, moved into lungs and passed through gastrointestinal tracts of small mammals. Among those which were absorbed and deposited in animal tissues in significant amounts were isotopes of cobalt, manganese, and tungsten. Some additional results relating to activation products in Sedan fallout already

Table 2. Relative concentrations of ^{90}Sr, ^{137}Cs, and ^{144}Ce in samples of soil, plants, and small mammals (Dipodomys spp.) collected May 1966 and October 1967 from study sites in the Palanquin (U20K) fallout area.

Radionuclide	Year	Disintegrations/min./g dry weight						
		Soil[a]	Plant[b]	Bone	Muscle	Lung	Hide	G I tract
	Site no. 4, located 0.5 km downwind from ground zero							
^{90}Sr	1966	364	25.8	42.9	-	6.6	19.7	25.2
^{137}Cs	1966	679	38.3	-	9.6	14.8	12.7	40.9
^{144}Ce	1966	165	57.2	-	-	trace	12.5	50.5
	Site no. 3, located 1.0 km downwind from ground zero							
^{90}Sr	1966	112	8.2	35.8	-	12.3	28.5	25.7
	1967	-	3.7	63.5	-	8.7	22.6	41.4
^{137}Cs	1966	218	11.4	-	11.7	19.6	24.6	44.6
	1967	-	4.8	-	12.7	18.9	38.6	77.9
^{144}Ce	1966	177	17.8	-	-	trace	15.7	51.6
	1967	-	3.7	-	-	10.4	26.3	60.3
	Site no. 2, located 2.0 km downwind from ground zero							
^{90}Sr	1966	36	9.4	58.9	-	3.8	26.5	12.3
	1967	-	6.0	46.5	-	3.1	17.9	13.7
^{137}Cs	1966	62	4.8	-	13.2	26.4	47.3	32.0
	1967	-	4.7	-	8.0	19.4	14.4	32.1
^{144}Ce	1966	429	29.2	-	-	18.9	45.5	46.9
	1967	-	22.8	-	-	trace	26.4	9.6
	Site no. 1, located 3.0 km downwind from ground zero							
^{90}Sr	1966	20	5.3	30.7	-	6.2	59.0	16.1
^{137}Cs	1966	58	7.6	-	14.1	26.1	75.2	26.3
^{144}Ce	1966	102	12.9	-	-	8.5	22.5	69.1

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[a] 0-2.5 cm surface soil; [b] mixed grasses

Table 3. ^{90}Sr, ^{137}Cs, and ^{144}Ce contents of new grass grown in the U20K fallout area with and without protection from dust.

Species	Condition	^{90}Sr	^{137}Cs	^{144}Ce
		Disintegrations/min./g dry weight		
Stipa speciosa	protected	0.55	0.57	0.63
	exposed	3.45	4.27	3.42
Hilaria jamesii	protected	0.29	1.02	1.67
	exposed	1.94	7.72	11.94
Sitanion jubatum	protected	0.79	0.86	3.71
	exposed	6.89	1.15	6.61

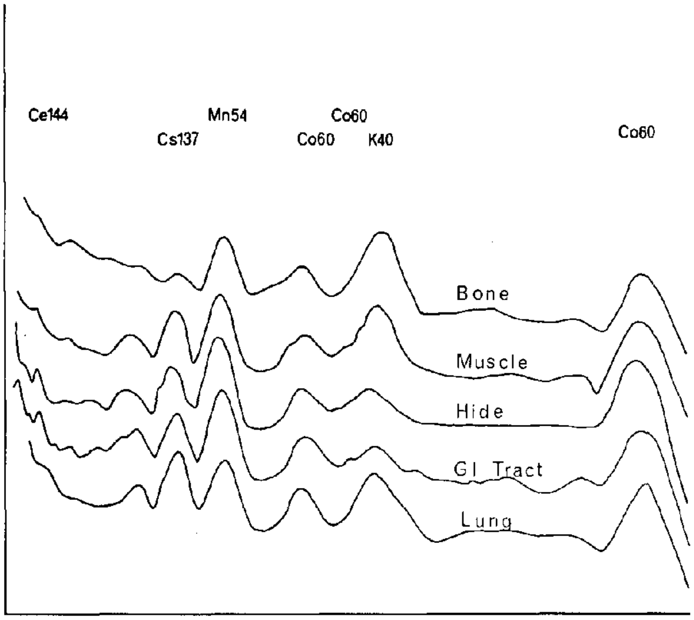

Figure 2. Gamma spectra of kangaroo rat (*Dipodomys* spp.) tissue samples from the Palanquin area 13 months after fallout occurred.

Figure 3. Gamma spectra of cottontail rabbit (*Sylvilagus* spp.) tissues sampled from the Palanquin area at different time intervals after fallout occurred on 14 April 1965.

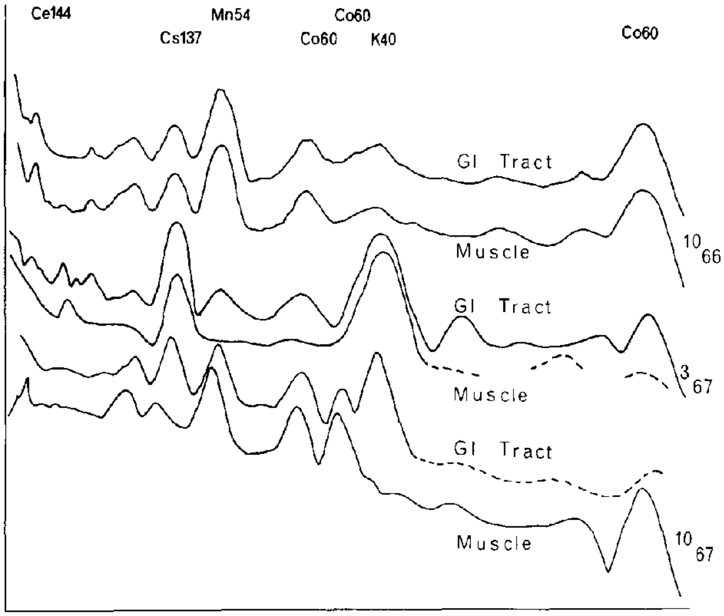

Table 4. Influence of chelating agents on root uptake of ^{90}Sr and ^{137}Cs by plants grown on potted soil collected from old fallout areas in southern Nevada and Utah.

Distance from G.Z. km	Treatment	Soil		Alfalfa		*F. dumosa*	
		^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs
		Disintegrations/min./g dry weight					
22	Control	8.2	7.4	7.2	0.39	19.7	1.16
	DTPA	8.2	7.4	6.6	0.51	18.9	1.01
	EDDHA	8.2	7.4	6.7	0.38	16.9	1.00
26	Control	26.8	15.4	11.4	0.68	13.8	1.85
	DTPA	26.8	15.4	10.7	0.27	14.4	1.72
	EDDHA	26.8	15.4	12.6	0.36	12.9	1.71
109	Control	9.6	6.6	6.0	0.15	8.6	1.35
	DTPA	9.6	6.6	5.4	0.17	7.6	1.23
	EDDHA	9.6	6.6	4.6	0.13	9.5	1.95
160	Control	5.3	7.1	16.0	0.28	34.1	1.37
	DTPA	5.3	7.1	14.8	0.28	32.6	1.16
	EDDHA	5.3	7.1	15.9	0.28	32.5	1.05

Residence time of radionuclides in soil was about one decade.

Table 5. Influence of chelating agents on root uptake of ^{90}Sr and ^{137}Cs by plants grown on potted soil collected from close-in sites in the fallout pattern from the Palanquin (U20K) nuclear excavation test.

Distance from G.Z. km	Treatment	Soil		Alfalfa		*F. dumosa*	
		^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs
		Disintegrations/min./g dry weight					
0.5	Control	364	679	121.2	0.97	144.4	1.67
	DTPA	364	679	66.3	0.51	146.3	1.72
	EDDHA	364	679	100.2	0.81	110.7	1.53
1.0	Control	112	218	76.3	1.22	153.6	2.30
	DTPA	112	218	55.8	0.77	88.1	1.35
	EDDHA	112	218	55.3	0.68	105.2	1.33
2.0	Control	36	62	66.5	0.84	118.4	3.37
	DTPA	36	62	45.1	0.73	81.7	1.12
	EDDHA	36	62	46.5	0.53	78.6	1.98
3.0	Control	20	58	57.5	0.78	101.9	1.89
	DTPA	20	58	46.7	0.71	96.7	2.15
	EDDHA	20	58	56.7	0.87	83.9	2.17

Residence time of radionuclides in soil was about three years.

have been reported (Romney et al., 1966; Romney and Rhoads, 1966). Inasmuch as most neutron activation products are relatively short-lived, their biological significance in fallout sharply decreases with passing time. The radionuclide concentrations in these close-in fallout areas probably represent some of the worst-case possibilities of environmental contamination. Fortunately, these fallout patterns from nuclear excavations are relatively small and confined to close-in areas when compared to those from earlier above-ground tests. Radiological effects on the native vegetation in these close-in fallout areas have been reported (Rhoads et al., 1966a, and b, 1970).

Table 3 contains data which illustrate how plant material growing in a fallout area is further contaminated by redeposited fallout debris. Protection of native grasses was provided by framed enclosures which had clear plastic covers and medical filter-media cloth sides. Significant reduction of ^{90}Sr, ^{137}Cs, ^{144}Ce, and other radionuclides in plant samples was affected by this protection. External contamination was a greater source of radionuclides in plant forage than root uptake from soil. Our success in protecting plant material from fallout debris with these covers prompted a similar application in the Schooner (1968) fallout pattern wherein large plastic covers adequately protected native vegetation from destruction by beta irradiation from fallout debris. Rhoads et al. (1970) reported on this work. See also page 56.

Results of glasshouse pot tests on ^{90}Sr and ^{137}Cs uptake through plant roots are shown in Tables 4 and 5. Higher levels of ^{90}Sr than ^{137}Cs were taken up by both alfalfa and the native desert shrub (Franseria dumosa) and this shrub contained higher levels of ^{90}Sr and ^{137}Cs than did alfalfa. The addition of chelating agents did not significantly influence plant uptake of ^{90}Sr and ^{137}Cs through plant roots. These pot tests indicate that root uptake of ^{90}Sr and ^{137}Cs increased about ten-fold when grown on soil in which the initial surface-deposited fallout debris was thoroughly mixed in the root zone compared to field grown plants. Radionuclides taken up by plant roots and those in dust particles adhering to foliage are probably the main dietary source of contamination to small mammals living in fallout areas.

Summary

The persistence of radionuclides in soil, plants, and small mammals was investigated in 1966 in areas that had been contaminated with fallout from above-ground nuclear detonations at the Nevada Test Site during the period 1952-1959. Study sites were established at various locations out to about 225 km from ground zero. Emphasis was placed upon the movement of ^{90}Sr and ^{137}Cs from abiotic to biotic components. Several neutron activation products also were studied in fallout areas located within 5 km of recent nuclear excavation tests. Radionuclides continued to be taken up through plant roots in small amounts as time progressed, and some continued to be deposited on foliage as resuspended dust particles. The inhalation route of entry became less important with passing time, whereas ingestion continued to be the most important route through which radionuclides entered small mammals living in old fallout areas. Long lived ^{90}Sr accumulated primarily in bone tissue while ^{137}Cs accumulated in muscle and soft tissue. Most of the neutron activation products are short-lived, but among those found in animal tissues were isotopes of cobalt, manganese, and tungsten. Findings indicate that ^{90}Sr and ^{137}Cs will continue to move in small amounts from abiotic to biotic components in fallout-contaminated areas with passing time.

SENSITIVITY OF DESERT PLANTS TO ACUTE GAMMA RADIATION

Laboratory experiments were conducted to compare the sensitivity of some desert plants to acute gamma radiation from a 10,000 curie ^{60}Co source. Rhoads et al. (1969) irradiated a natural area on Pahute mesa for 34 days with a 1,000 curie ^{60}Co source. They observed Ephedra viridis to be most sensitive to the radiation followed by Juniperus osteosperma, Artemisia tridentata, A. arbuscula, and Grayia spinosa. In nearby areas damaged by fallout, the Artemisia species appeared more sensitive to fallout radiation than either Ephedra or Juniperus. This was later shown to result partly from larger numbers of fallout particles trapped on the foliage of Artemisia compared to other species, subjecting it to higher levels of beta radiation. Another point suggested by these field studies was a reduced sensitivity of plants when irradiated during dormancy.

Materials and Methods

Desert plant species produced from seeds and rooted cuttings were used in these experiments. Much effort was spent developing methods of propagation for producing succulent specimens and methods for maintaining the plants in a succulent, vegetative stage. Preliminary tests had shown that the amount of variability encountered in radiation response was unacceptable for experimental studies when dormant or semi-dormant materials were used. The radiation sensitivity of dormant plants is a separate problem involving additional studies; those findings reported here involved succulent cuttings and seedlings only. One general observation at this point is that dormancy may reduce the radiation sensitivity by more than a factor of ten for some woody, perennial species.

Most of the woody plant materials used were vegetatively propagated. Seedlings, when available, were the source of cutting materials; terminal cuttings 2 to 4 inches in length were used. Upon rooting, the succulent cuttings and seedlings were transplanted to plastic pots and grown for 1 to 6 months before treatment. If too large or woody, they were pruned to maintain a manageably sized, vigorously growing plant. Considerable husbandry was required to provide plants of uniform growth and similar size and shape for the radiation exposure tests. Replication of treatment levels and repetition of experiments were both used to verify results. Young deciduous plants had a tendency to be evergreen in laboratory culture, although once they became dormant they usually remained in that state. It was difficult to break dormancy.

The ^{60}Co source consisted of a series of pencil-type containers arrayed on a base mount as shown in the mock-up photograph in Figure 1. Plants were placed about the source in circles or arcs at varied distances to achieve different exposure levels. Plants were placed on individual turn tables rotating about 6 rpm. Different radiation treatment levels were obtained by varying the time of exposure and the distance from the source. Findings reported are for specimens irradiated without additional shielding of roots other than that contributed by the potted soil surrounding the roots.

Irradiated plants were returned to growth areas and cared for to avoid water stress, insect damage, and over-watering. After several preliminary tests, a method of scoring plant responses to radiation was selected. Special consideration was needed for each species (clone) individually; therefore, scoring was done for each species at different times after irradiation. We selected as criterion for lethal dose the minimum level of acute gamma radiation at which death occurred. This differs from the conventional LD_{100} rating of minimal dose killing 100% of a plant population. The problems of producing large populations of the relatively slow-growing desert shrubs, and maintaining them in a succulent, vegetative state during the course of each test, forced us to use this scoring system involving only two to five replicates per radiation level. The tests on each different species usually involved two or more phases, the first of which encompassed a wide range of exposure levels, followed by further tests in which the range was narrowed down to, and concentrated about, the levels of suspected lethal dose.

Figure 1. Mock-up of desert plant species being irradiated by a 10,000 curie ^{60}Co source. Specimens were arranged about the source on individual turntables rotating at about 6 rpm.

Results and Discussion

Results are given in Table 1 for some 30 desert plant species ranked in order of decreasing sensitivity, according to the minimum level of acute gamma radiation at which death occurred. Although these findings represent only gross, visible responses, they are results from repeated tests. Histological and cytological work is necessary to verify and describe the nature of radiation damage involved. We have included some data provided by Dr. Arnold Sparrow's laboratory (Brookhaven National Laboratory, Upton, Long Island) for nuclear volumes and somatic interphase chromosome volumes (ICV) determined on samples of a few different species. In the field work on Pahute Mesa reported by Rhoads et al. (1969), the arrangement of genus in order of decreas-

Table 1. Sensitivity of desert plant species to acute gamma radiation ranked in decreasing order of sensitivity.

Species	Lethal dose kR	Scoring time month	Nuclear volume μ^3	ICV** μ^3
Machaeranthera tortifolia	2-3	7	-	-
Artemisia spinescens	2-3	7	-	-
Hymenoclea salsola	2-3	7	-	-
Gutierrezia microcephala	2-3	7	-	-
Ephedra viridis	2-3	12	631	45.1
Artemisia tridentata	3-4	26	487	13.5
Artemisia arbuscula	4-5	16	430	13.2
*Lycium andersonii**	4-7	26	466	9.7
Franseria dumosa	4-5	15	152	4.2
Eurotia lanata	4-5	15	-	-
Atriplex hymenelytra	4-6	16	-	-
Encelia virginensis	5-6	11	-	-
Cercidium microphyllum	5-6	11	-	-
*Grayia spinosa**	5-7	16	128	4.0
Haplopappus cooperi	6-7	7	-	-
Franseria eriocentra	6-7	7	-	-
Eriogonum fasciculatum	6-7	7	-	-
*Cowania mexicana**	6-10	7	93	5.2
*Coleogyne ramosissima**	6-10	16	-	-
Atriplex confertifolia	6-7	16	-	-
Atriplex lentiformis	7-8	15	-	-
Salsola iberica	9-10	3	176	4.9
Larrea divaricata	10-11	15	212	-
Atriplex canescens	10-11	14	198	-
*Lycium pallidum**	10-12	16	-	-
Kochia americana	10-11	7	-	-
Arabis pulchra	10-11	7	-	-
Salazaria mexicana	10-11	7	-	-
Yucca baccata	10-12	7	-	-
*Prunus fasciculata**	14-16	16	-	-
Yucca schidigera	25-27	32	292	4.9

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*Deciduous species difficult to score.

**ICV is interphase chromosome volume.

ing sensitivity to ^{60}Co irradiation was *Ephedra*, *Juniperus*, *Artemisia*, and *Grayia*, which was the same order as that of decreasing nuclear volumes or ICV of these genera. In this laboratory study, the plants involved again fell into the same order of decreasing radiation sensitivity and, along with others, generally showed decreased radiation sensitivity as nuclear volumes and ICV decreased. Some deciduous species, so noted, were difficult to score without doubt because of their inherent tendency to become dormant when subjected to environmental stress.

We must emphasize again that the radiation sensitivity of woody, perennial species is markedly influenced by the vegetative state of the plant when irradiated. Dormant plants of many different species could survive radiation levels from radioactive fallout which would destroy or severely damage actively growing plants.

Summary

The radiation sensitivity of some 30 different species of desert plants was compared in the laboratory using a 10,000 curie ^{60}Co source. Some deciduous plant species were difficult to score because of their inherent tendency to become dormant under environmental stress. Dormant plants survived much higher levels of radiation than actively growing plants. The findings reported here are for plants irradiated in a succulent, vegetative state. Based upon a limited amount of data, the order of decreasing sensitivity to acute gamma radiation generally was the same as the order of decreasing nuclear volume or ICV of the species.

^{90}Sr UPTAKE BY DESERT VEGETATION

Radioactive ^{90}Sr biologically is the most important of all fission products in radioactive fallout. This is not only because of the amount produced and its long half life, but particularly because it is deposited in bone tissue in much the same way as is calcium. Inasmuch as ^{90}Sr is a weak beta emitter, it is important as an internal emitter and its presence in the food chain is therefore of considerable concern. Recognition of the potential biological hazards from this fission product contributed strongly toward the agreements reached among world powers to discontinue atmospheric testing of nuclear devices.

Contaminated soils and plants are important links in the movement of ^{90}Sr through the food chain leading to man. The food chain includes animals upon which man depends for food. When fallout occurs, the radioactive materials are deposited on the soil surface and on the surface of plant foliage. Consequently, the plant material ingested by animals may be contaminated externally from adhering fallout particles and internally from absorbed radionuclides. Workers at this laboratory have investigated plant uptake of ^{90}Sr and certain factors influencing its reactions in the soil and plant links of the food chain. Earlier studies primarily have been concerned with agricultural systems and edaphic conditions involving food crop production (Nishita et al., 1956, 1958, 1961, 1968; Romney et al., 1957, 1959a, and b, 1960a, and b, 1961, 1963a, and b, 1966; Goss and Romney, 1959; Essington et al., 1962; Nishita and Taylor, 1964; Essington et al., 1965).

Experimental Results

Our development of methods to propagate and grow desert plants in artificial environments enabled us to investigate comparative uptake of ^{90}Sr in desert vegetation. Several different plant species were grown under glasshouse conditions in 10-kg lots of soil obtained from west Frenchman Flat and contaminated with ^{90}Sr (3200 dis/sec/g dry soil). The data in Table 1 indicate the plant growth periods and the concentration of ^{90}Sr and mineral elements found in leaf and stem tissues upon harvest. These uptake levels, which occurred under choice environmental conditions, are thought to represent the worst case of ^{90}Sr uptake one might expect under natural desert conditions.

Some interesting trends occur in these data. Uptake of ^{90}Sr varied considerably among the species investigated. It was lowest in Oryzopsis hymenoides, a common range grass, and intermediate in Eurotia lanata, one of the most preferred of these species by grazing livestock. The four Atriplex species studied were among the highest and lowest in ^{90}Sr uptake, and two of these species, A. confertifolia and A. hymenelytra concentrated high levels of ^{90}Sr in stem tissue. Several other species studied concentrated as much as three times more ^{90}Sr in leaves as in stems; their stable strontium levels followed a similar pattern. Notable examples are A. canescens, E. lanata, and Chrysothamnus nauseosus. Tissues containing the highest levels of ^{90}Sr also contained the highest levels of stable strontium and, in addition, they also contained the highest levels of calcium and potassium. An exception of this was A. confertifolia stem tissue.

Correlation coefficients for ^{90}Sr in leaves × various cations in leaves (Table 2) indicate that the highest value was for ^{90}Sr × stable strontium. Smaller values were obtained with calcium, potassium, barium, or sodium + potassium + calcium + magnesium. The implication is that ^{90}Sr (and stable stron-

Table 1. ^{90}Sr and mineral element composition of desert plants grown in west Frenchman Flat soil under glasshouse conditions.

Plant species growth period (days)	Plant part	^{90}Sr content	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Al	Sr	Ba	Na+K +Ca+Mg	Specific activity of ^{90}Sr
		d/m/g	% of dry weight					ppm of dry weight								me/ 100 g	d/m/g / µg Sr
Artemisia	leaf	18,971	.40	0.067	2.31	0.74	.19	33	26	33	115	73	35	47	9.3	115	404
tridentata (270)	stem	17,368	.23	0.019	2.01	0.33	.13	48	23	35	64	20	29	43	7.2	80	404
Astragalus	leaf	29,757	.26	0.043	3.75	1.28	.38	60	5	87	67	107	107	40	4.1	193	744
lentiginosus (60)	stem	27,955	.16	0.011	3.80	0.72	.27	58	5	49	33	46	93	42	6.2	156	666
Atriplex	leaf	76,887	.20	0.039	10.62	1.78	.81	116	6	91	78	40	65	76	12.0	430	1012
canescens (270)	stem	37,608	.18	0.011	2.25	0.38	.35	22	10	65	65	14	57	38	10.9	106	990
Atriplex	leaf	74,215	.29	1.450	9.47	1.87	.72	77	13	170	82	37	52	72	8.2	459	1031
confertifolia (270)	stem	82,164	.23	0.107	2.89	0.89	.29	40	8	34	98	14	20	73	7.9	147	1126
Atriplex	leaf	27,514	.24	1.539	11.22	1.44	.63	76	7	63	97	46	55	37	13.0	479	744
hymenelytra (270)	stem	61,738	.26	0.788	3.14	1.31	.19	49	6	25	64	24	53	57	8.2	196	1083
Atriplex	leaf	21,494	.11	1.058	7.17	1.31	.70	43	4	59	113	93	64	43	5.5	353	500
polycarpa (270)	stem	13,279	.18	0.578	2.08	0.33	.27	57	11	22	100	12	8	37	4.9	117	359
Chrysothamnus	leaf	11,357	.23	0.162	3.49	1.06	.31	96	15	439	121	189	539	37	10.5	175	307
nauseosus (270)	stem	9,278	.13	0.046	2.34	0.20	.14	79	24	369	24	22	396	26	11.3	84	356
Descurainia pinnata (60)	top	42,247	.41	0.003	5.02	0.55	.32	127	10	68	67	61	60	34	4.2	183	1243
Eurotia	leaf	36,966	.13	0.067	2.81	1.29	.42	32	5	65	73	101	45	54	5.1	174	685
lanata (270)	stem	9,706	.11	0.004	1.97	0.27	.13	51	11	30	39	9	12	24	3.9	75	404
Franseria	leaf	59,652	.41	0.163	3.41	3.78	.72	53	42	34	59	353	87	66	9.2	353	904
dumosa (270)	stem	42,151	.28	0.045	3.17	0.60	.29	44	16	65	34	30	12	49	8.7	137	860
Larrea	leaf	16,380	.19	0.035	3.14	1.12	.20	27	10	165	30	66	289	43	7.2	155	381
divaricata (270)	stem	15,738	.17	0.011	2.10	0.75	.16	29	9	55	20	10	68	50	6.2	105	315
Lycium	leaf	75,445	.45	0.043	8.13	2.51	.56	56	27	198	84	163	266	72	26.0	382	1048
andersonii (270)	stem	21,101	.14	0.003	1.21	0.84	.12	98	14	35	18	7	31	49	7.0	83	431
Oryzopsis hymenoides (270)	top	9,297	.11	0.021	3.93	0.44	.21	243	79	78	59	78	26	35	13.0	141	266
Yucca schidigera (300)	top	43,707	.28	0.006	1.86	1.36	.45	65	21	111	47	31	44	52	5.0	154	841

tium) is transported at least in part independently of other cations.

Table 2. Correlation coefficients for ^{90}Sr and strontium in leaves or tops with cations in leaves or tops of desert plants grown in west Frenchman Flat soil.

Factors correlated	r
^{90}Sr x Ca	0.647
^{90}Sr x Sr	0.898
^{90}Sr x K	0.509
^{90}Sr x Ba	0.346
^{90}Sr x Ca + Mg + K + Na	0.645
Sr x Ba	0.395

Leaf-stem ratios of various cations (Table 3) indicate that the greatest correlation coefficient between distribution of ^{90}Sr and cations was for ^{90}Sr x stable strontium. There was a negative relationship between the distribution of ^{90}Sr and of calcium. These data also indicate that transport of ^{90}Sr (and stable strontium) is considerably independent of that of other cations. The source of stable strontium in the plants was from the soil rather than with the ^{90}Sr application.

Table 3. Leaf-stem ratios for quantities of various cations calculated from data in Table 1.*

	^{90}Sr	K	Ca	Sr	Ba	Na+K +Ca+Mg
Artemisia tridentata	1.09	1.15	2.24	1.09	1.29	1.44
Astragalus lentiginosus	1.06	0.99	1.78	0.95	0.66	1.24
Atriplex canescens	2.04	4.72	4.68	2.00	1.10	4.06
Atriplex confertifolia	0.90	3.28	2.11	0.99	1.04	3.12
Atriplex hymenelytra	0.45	3.57	1.10	0.65	1.59	2.44
Atriplex polycarpa	1.62	3.45	3.97	1.16	1.12	3.02
Chrysothamnus nauseosus	1.22	1.49	5.30	1.42	0.93	2.08
Eurotia lanata	3.81	1.43	4.78	2.25	1.31	2.32
Franseria dumosa	1.42	1.08	6.63	1.35	1.06	2.58
Larrea divaricata	1.04	1.50	1.49	0.86	1.16	1.48
Lycium andersonii	3.58	6.72	2.99	1.47	3.71	4.60

*Correlation coefficients were for ^{90}Sr x K, +0.39; ^{90}Sr x Ca, -0.36; ^{90}Sr x Sr, +0.80; ^{90}Sr x Ba, +0.58; and ^{90}Sr x Na + K + Ca + Mg, +0.52.

Data in Table 1 indicated some variation in the specific activity (d/m/g ^{90}Sr/μg Sr) of ^{90}Sr in the plants. There was some indication that the plants with high cation levels in leaves had higher specific activities than plants with low cation levels in leaves. The correlation coefficient between the cation me sum in leaves x the specific activity was 0.74. This seems to account for part of the variability. This probably has some bearing on the mechanisms by which the different species extract cations from soil.

Summary

The levels of ^{90}Sr uptake varied among different species of desert vegetation. A species of range grass, Oryzopsis hymenoides, had the lowest ^{90}Sr content of the species investigated and,perhaps significantly, the lowest specific activity of ^{90}Sr per stable strontium of all the species. Highest uptake of ^{90}Sr occurred in Atriplex confertifolia, Atriplex hymenelytra and Lycium andersonii. Nearly the same levels of ^{90}Sr concentrated in leaf and stem tissues of Artemisia tridentata, Astragalus lentiginosus, and Larrea divaricata. In A. confertifolia and A. hymenelytra the ^{90}Sr was concentrated highest in stem tissue. The other species studied concentrated as much as three times more ^{90}Sr in leaf tissues as in stems. A similar distribution pattern occurred for the stable strontium levels in leaf and stem tissues of these desert plant species. A higher correlation coefficient was obtained for ^{90}Sr x strontium than for ^{90}Sr x other cations or sum of cations. The leaf-stem ratio for the ^{90}Sr was more correlated with the leaf-stem ratio for stable strontium than with other cations. There was a positive correlation between specific activity of ^{90}Sr and the cation sum of leaves.

THE EFFECT OF ^{60}Co-RADIATION ON EMERGENCE AND SEEDLING GROWTH OF *LYCIUM PALLIDUM* AT TWO LEVELS OF HYDRATION

On March 16, 1970, 20 seed of *Lycium pallidum* were placed in each of five vials for each of five lots of seed, lots 3, 6, 7, 12, and 13, respectively. At this time similar sets of 20 seed each, five sets per each of the five lots, were counted out and placed in vials of moist peat. These vials were placed in a refrigerator at 5°C until March 25, 1970, at which time the seeds were removed from the vials of peat and placed in clean vials.

On March 25, 1970, one vial of dry and one vial of moist seed of each of the five seed lots was given, respectively, 0, 5 kR, 10 kR, and 20 kR of ^{60}Co-radiation. The seeds of the remaining vial for each level of hydration and lot were oven dried at 105°C for 24 hours to establish the moisture content of the seed (Table 1).

Table 1. The moisture content and the dry weights of seeds of *L. pallidum* used in the radiation experiment.

Lot	Dry seed		Moist seed	
no.	Dry wt mg/seed	H_2O % dry wt	Dry wt mg/seed	H_2O % dry wt
3	18.3	5.6	14.7	60
6	21.3	6.3	16.6	87
7	16.3	8.7	12.8	57
12	22.6	9.3	16.7	76
13	18.2	5.6	15.6	73
means	19.3	7.1	15.3	71

Immediately after radiation treatment the seed was sown in fine vermiculite in clay pots and placed in the glasshouse (temperature range 15to 25°C) to observe emergence.

Seed emergence began in about 10 days, and continued at a diminishing rate for several days. On June 17, 1970, the emerged seedlings were counted; at this time no new seedlings had emerged for several days. The percentage emergence of non-irradiated seed (controls) for the seed lots 3, 6, 7, 12, and 13 was respectively 8, 35, 42, 2, and 0 %. This type of variability is common for lots of seeds obtained from the field. A few seedlings had emerged from the irradiated seeds, but the overall emergence of lots 3, 12, and 13 was so poor that the data to follow pertaining to emergence of seedlings following ^{60}Co irradiation of seed is limited to lots 6 and 7. Seed of these lots behaved similarly, and the data of the two lots are combined. Status of emergence and survival of seedlings as of June 17, 1970 are given in Table 2.

Indications of this study are that dry seed of *L. pallidum* will tolerate 10 kR of radiation and that moist seed will tolerate 5 kR, without significantly diminishing the emergence of seedlings or their early survival. At radiation levels much in excess of these, however, the rate of emergence declines

Table 2. Effect of seed hydration and irradiation on emergence and survival of L. pallidum seedlings 90 days after seeding.

Radiation level kR	Condition of seed at time of radiation	Seedlings from 40 seed per treatment	
		Live	Dead
0	dry	13	0
0	moist	18	0
5	dry	17	1
5	moist	13	1
10	dry	13	2
10	moist	1	6
20	dry	1	1
20	moist	0	0

sharply, and the emerged seedlings have a low survival rate. The increase of sensitivity to ionizing radiation with increasing water content of seeds is a fairly general phenomenon and has been reviewed in the literature (Möes, 1961).

R. T. Ashcroft is the principal author of this report.

REVEGETATION IN AREAS DAMAGED BY CLOSE-IN FALLOUT FROM NUCLEAR DETONATIONS

Nuclear tests have in many cases destroyed the natural vegetation at the Nevada Test Site either because of fire or blast (Martin, 1963) or from radiation (Rhoads et al., 1969a and b, 1970). The purpose of this report is to describe observations relating to revegetation of areas in which plant cover was previously destroyed by nuclear testing activities.

Materials and Methods

In September 1967 three study plots (30 m x 30 m) were established at about 2000 m elevation on Pahute Mesa in an *Artemisia tridentata* and *Artemisia arbuscula* subsp. *nova* community. Two years previously, in April 1965, a plowshare nuclear cratering event (Palanquin) had resulted in a gradient of plant destruction beginning with complete destruction near ground zero and extending downwind with progressively less destruction to a distance of about 5 km. One of the plots was established in an area where total destruction had occurred. Another was located in an area of about 80 to 90 per cent destruction. The third plot was established as a control plot in an adjacent area completely devoid of destruction. A partial census of plant populations was made in the plots on 11 September 1967 and on 21 May 1969.

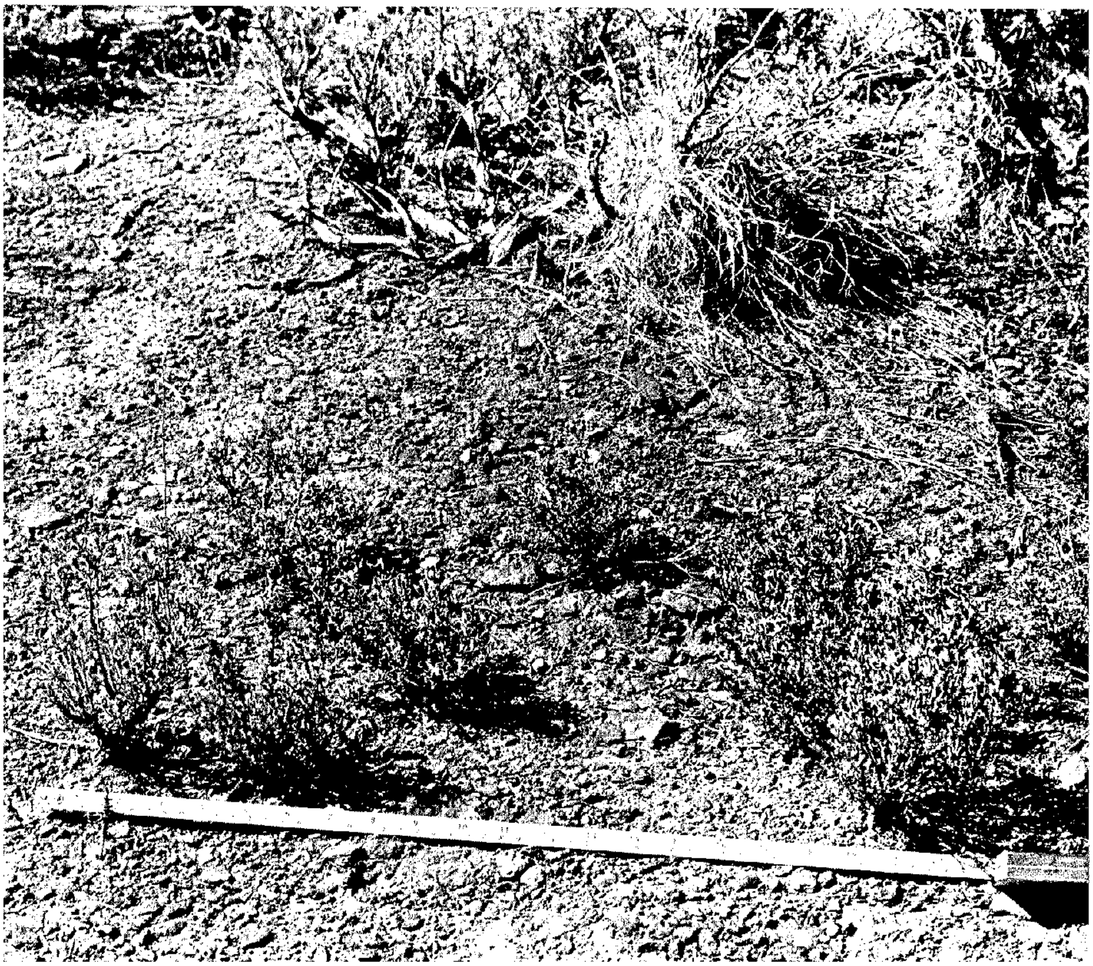
In July 1962 the Sedan plowshare cratering event resulted in considerable burial of shrubs by ejecta, and blast damage to shrubs (Martin, 1963; Nordyke and Williamson, 1965; Beatley, 1965a, b, 1966). In 1969 some observations on plant distribution were made close in to the ground zero in areas where the original vegetation had been covered by throwout ejecta or destroyed by blast. Since the Sedan event the *Salsola* species had grown in the damaged area in great abundance (Beatley, 1965; Koranda, 1967). The major reason for the 1969 investigation was to explain the low incidence of *Salsola* species in 1969.

Results and Discussion

On 11 September 1967 the undisturbed control plot on Pahute Mesa contained about 1000 live *Artemisia tridentata* plants and remains of 300 which had died of natural causes. With a proportion of 25 to 30% dead shrubs, their average life span would not be great; we estimate it to be from 30 to 40 years. If decomposition of the dead ones required 10 years on an average, then probably about 30 shrubs die per year. In order to maintain a population of 1000 then, an average of 30 new seedlings per year would be required. In 1967 there were six new seedlings in the plot; in 1969 there were 13; and in 1970 there were 14. Most of these in 1970 were the same ones present in 1969; however, so that for this 3-year period the number of new seedlings per year did not approach 30. Numbers of annual growth rings on representative shrubs indicate that 67 was the maximum number at this plot. A comprehensive study of growth rings in the species was made by Ferguson (1960) who found that the number could go over 100. Also in this plot in 1967 were approximately 100 clumps of grass, mostly *Oryzopsis hymenoides*, *Poa sandbergii*, *Hilaria jamesii*, and *Sitanion jubatum*. In May of 1969 there were approximately 800 clumps of grass in the plot; the increase was mainly *P. sandbergii*. In 1967 this plot had 85 *Ephedra nevadensis* and 14 *Grayia spinosa*. These numbers were unchanged in 1969 and 1970. There were no *Salsola* species in this plot in any of the years of the investigation.

In the plot partially destroyed by the test event, there were over 1000 dead A. tridentata in 1967 with 80 live specimens remaining from the old population. Some of these were partially damaged but they still produced mature seed in 1967. In 1970 all 80 of these original plants were still alive. In 1967 there were 35 new A. tridentata seedlings in the plot, and in 1969 these were still there and new germinations since that time resulted in a total of 240 seedlings in the plot. On 12 July 1970 the number of seedlings had increased to 390. Prior to 1969 the new seedlings did not grow near any of the old shrubs whether dead or alive; they germinated in the open areas between the shrubs (Figure 1). Allelopathy (Muller, 1966) may be involved. In 1967 there were 60 E. nevadensis in the plot and in 1969 there were three more. In 1967 there were 20 G. spinosa in the plot and they were still there in 1970. In 1967 there were eight Lycium andersonii in the plot and in 1969 and 1970 there were eight. In 1967 there were five Eurotia lanata with the same number present in 1970. In 1967 there were about 400 clumps of grass in the plot (O. hymenoides mostly) representing seven per cent ground cover by grasses. In 1969 there

Figure 1. New Artemisia seedlings have germinated and established themselves in open areas between original shrubs destroyed by radioactive fallout from the Palanquin test.



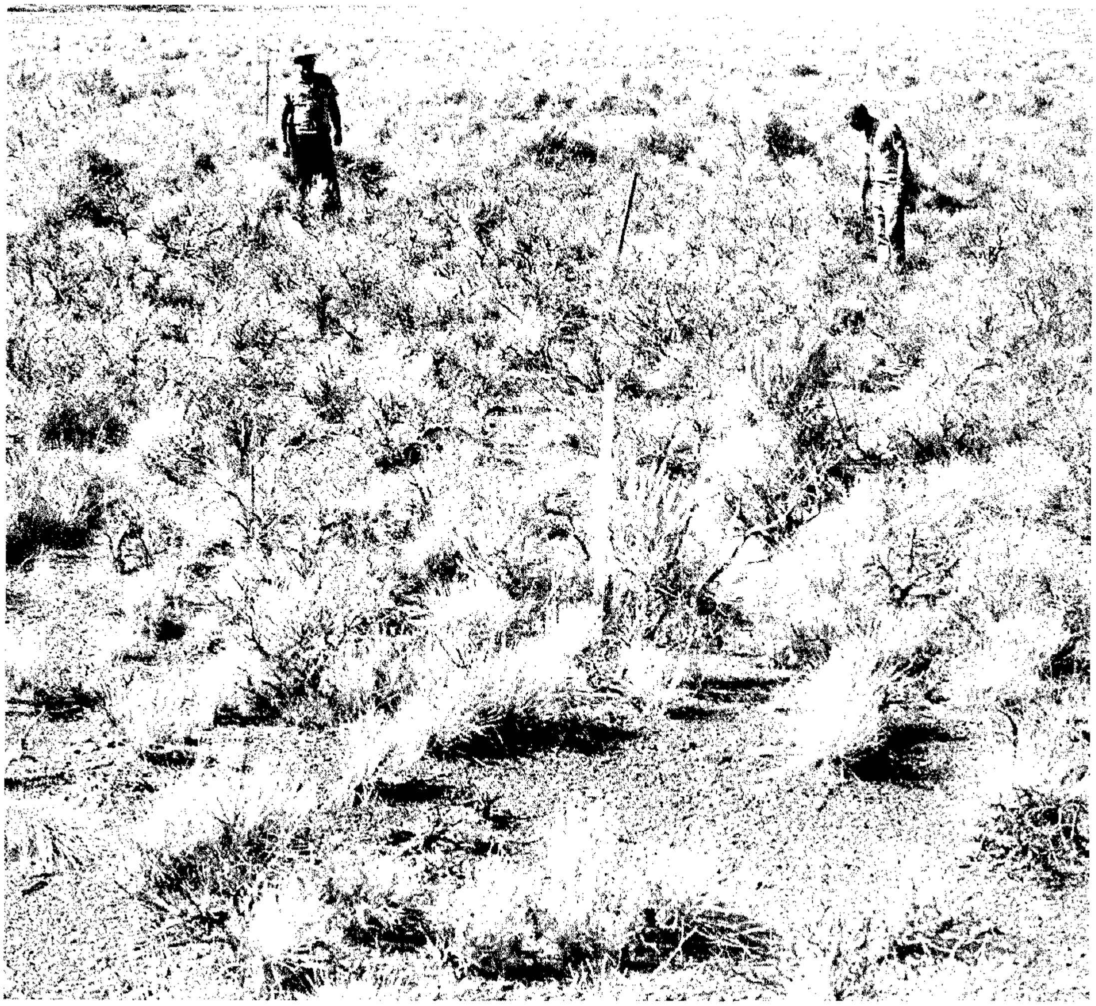


Figure 2. View of the area partially destroyed by fallout radiation. Note the influx of grass within a 3-year period.

were approximately 5000 clumps (mostly S. jubatum and H. jamesii) with a 28 per cent ground cover (Figure 2). Partial destruction of the A. tridentata had resulted in changing the plot to a grassland. How long is necessary for the area to revert back to predominately Artemisia will be followed. In 1967 there were very few Salsola species in the plot and none in May 1969, at which time there were numerous Astragalus purshii present. In September 1967 there were hundreds of Machaeranthera leucanthemifolia. In July 1970 there were essentially no annuals as was the case generally around the Nevada Test Site as the result of seasonal drought conditions.

In the fully disturbed plot in September 1967, the vegetation was predominately Salsola iberica and Salsola paulsenii, M. leucanthemifolia, and O. hymenoides. In 1966 there had been a few Salsola plants in the plot and their seed may have been necessary for the 1967 population which numbered approximately 7500 on the plot (Figure 3). Each plant was over 30 cm tall in September. In 1969 there were a large number of Salsola plants but they did not grow more than about 5 cm high due to drought conditions. The summer of 1969 was a poor year for Salsola germination in spite of abundant early spring moisture. Winter and spring moisture did not penetrate into frozen soil partially due to an early spring thaw which caused heavy water runoff and flooding. In 1967 there were approximately 1600 dead A. arbuscula, subsp. nova in the plot with no live ones. In 1967 there were 111 new seedlings but in 1969 there were only five remaining. One was about 50 cm tall so it is possible that it was the only one surviving of the 111 and that the other four were new seedlings since 1967. Possibly dense cover from the Salsola species killed the Artemisia seedlings in this plot coupled with the 1969 and 1970 droughts. Only two Artemisia seedlings remained in this plot in 1970. It can be expected that germination would occur if seed were available. In 1967 there were about 450 clumps of grass, mostly S. jubatum. This plot also has tended to change to grassland but at a slower rate possibly due to competition from Salsola species. In 1967 there were 15 new G. spinosa seedlings in the plot and in 1969 the total number for this species was 23. In 1970 it was 25. Since the population is of the same magnitude as that of the undisturbed plot one can conclude that this species can easily reestablish itself after all the shrubs from a plot are destroyed. What role this species may play in the development of a climax under the circumstances is unknown. Also new in 1967 were two Eurotia lanata, one

Figure 3. View of area in which the original vegetation was destroyed by radiation. Note the influx of Salsola species and some mixed grasses within the 3-year period.

E. nevadensis, and two *Tetradymia axillaris*. In 1969 there were four *E. lanata*, four *T. axillaris*, and two *Chrysothamnus nauseosus*. In 1967 there was much *Astragalus purshii* in this plot.

Following the Cabriolet test in January 1968 when some plant cover was largely destroyed over a modest area (Rhoads et al., 1969) large numbers of *A. arbuscula* subsp. *nova* seedlings germinated. Two years later many of these had inflorescences. Plant response and climatological behavior since that event indicated that two or even three consecutive years of favorable moisture seems to be necessary for seedling survival of this species. The first year would result in seed set (severe drought seems to hinder the process), the second in germination, and the third in successful establishment and survival. This combination of circumstances occurs rarely.

In late May of 1969 near the Sedan crater (100 m from crater lip) the *Salsola* species had germinated at below normal levels. Further investigation showed this to be the result of the unusually cool spring months and these summer annuals merely germinated later in the year. A few *L. andersonii* shrubs are growing about 300 m from the edge of the Sedan crater. They appear to be new shoots from old crowns not completely killed by the ejecta and blast. Either regrowth was slow or browsing animals had eaten the new growth as it appeared. A large number of animals are in the area; they appear to like the soft surface provided by the throwout material around the Sedan crater. The major plant species for years has been *Salsola* species and some winter annuals which probably provide food for the rodents involved. Also in the area were a few *Atriplex canescens* plants; they mostly, however, were near a roadway where perhaps soil moisture is more favorable than in the open area. Actually *A. canescens* is probably the only shrub species germinating and surviving in the disturbed area after 8 years. Mixed grasses are becoming dominant in some areas around the Sedan crater.

In the spring of 1969 in order to study some aspects of shrub reestablishment, some seedlings of different shrub species native to the Nevada Test Site were transplanted at two different locations. Within a few days the seedlings had been eaten off by animals to the ground level. Considerable success has been experienced elsewhere on desert revegetation, e.g., report of A. P. Plummer, Restoring Big Game Range in Utah, Pub. 68-3. Utah Div. of Fish & Game, 1968.

Summary

Revegetation changes have been followed in the close-in fallout area of a plowshare nuclear test which killed most of the native vegetation in one area and severely damaged it in others. The *Artemisia* species dominate the vegetation of this area at Pahute Mesa. In the partially damaged area, *Artemisia* seedlings are reestablishing themselves but the area has become a grassland and few *Salsola* are present. Allelopathy may be involved in germination of new *Artemisia* seedlings. In the completely damaged area, *Salsola* populations have been dense and a new population of *Artemisia* seedlings have died. *Grayia spinosa* and to a lesser extent *Eurotia lanata*, *Ephedra nevadensis*, *Tetradymia axillaris* and *Chrysothamnus nauseosus* have successfully reestablished themselves. At the disturbed area around the Sedan crater only *Atriplex canescens* of the original perennial shrubs has germinated and survived. Some *Lycium andersonii* have survived near the crater (300 m away) with new growth sprouting from old crowns. *Salsola iberica* and *Salsola paulsenii* have been the principal plant species in this area since the event. There is evidence that browsing animals present could prevent recovery of shrubs in the area by eating any new seedlings which germinate or new shoots which sprout from old crowns.

CHARACTERISTICS OF EUROTIA LANATA (WINTERFAT)

Eurotia lanata (Pursh) grows over much of the desert and range land of the western United States, particularly in the Great Basin Desert, and is valued as an important forage shrub (Figure 1)(Cook and Hurst, 1962; Statler, 1967). It grows in both the Great Basin and Mojave Desert portions of the Nevada Test Site.

Shreve and Wiggins (1964) describe E. lanata as follows:

> Eurotia lanata (Pursh) Moq., Chenop. Enum. 81, 1840.
>
> Erect shrub 2.5 - 9 dm tall with slender, leafy branches densely tawny-stellate-tomentose and with intermingled simple hairs when young, becoming glabrate and with tawny to light gray, thin bark in age; leaves alternate with fascicles of smaller ones in their axils, linear-oblong to linear-lanceolate, 1 - 4 (or rarely 8) mm wide, 1 - 3.5 (or rarely 5) cm long, densely but finely stellate-lanate, hairs tawny to brownish, margins entire and narrowly revolute, acute at apex, cuneately narrowed at base to petioles 1 - 5 mm long or sessile; flowers monoecious, crowded in tight clusters in upper axils; calyx lobes of staminate flowers about 1 mm long, short-pubescent, margins scarious; fruiting bracts 4 - 8 mm long, densely long-villous with rusty, simple hairs 3 - 6 mm long; utricle ovoid-lenticular, lanate, seeds free from pericarp.
>
> Arid regions, Lower and Upper Sonoran Zones, eastern Washington to Saskatchewan and southward east of the Sierra Nevada to Texas, Sonora, and central Baja California. April - July.

Figure 1. Pistillate and staminate forms of E. lanata. Munz and Keck (1959) say that E. lanata can be either monoecious or dioecious.

Studies made of E. lanata in Wyoming resulted in the following conclusions (Riedl et al., 1964):

> Studies of Eurotia lanata were made to learn how this valuable forage shrub can be improved and established on western rangeland. The seed can be threshed satisfactorily with a nursery thresher and processed by means of various-sized screens, a fanning mill, and a South Dakota seed blower. The germination percentage of seed collected from 6 locations in 1958 and tested in 1959 varied from 47 to 78 percent. There were significant differences in germination of seed collected from different locations on the same date and on different dates at the same location. In general, seed collected on the later dates germinated better. Results also indicate that seed matured earlier at high altitudes than at low altitudes. Large seed size was associated more with rapidity of seedling emergence than with total germination. Selection for large seed types may improve seedling establishment. There were significant differences in the mean vigor of seedlings produced from seed collected at different locations. There was a wide range in seedling vigor produced from seed collected at the same location on the same date. These results indicate that it may be possible to select superior seedling-vigor lines. Seed collected northwest of Taos, New Mexico, produced a significantly better stand when planted in flats in the greenhouse than seed collected in Wyoming, Nevada, and other New Mexico locations. In general, the high seedling-vigor selections produced more forage than the low seedling-vigor selections during the three succeeding years after they were transplanted to the field. Chemical analyses of the forage showed that the crude protein varied from a high of 17.08 percent on Aug. 15 to a low of 8.08 percent on Oct. 14. The crude-protein percentage generally decreased, and crude fiber increased, as the plant matured. Soil samples obtained from sites where E. lanata was growing were relatively high in pH and carbonates and low in soluble salts and exchangeable sodium. A count of annual rings in the cross-section of E. lanata roots indicate it is a long-lived species (74 rings). Plants grew better at night temperature of 40°F than at 20°F, 10°F, and -10°F. Those grown at a night temperature of -10°F died. Plants exposed to 16 hours of light daily were significantly larger than those exposed to 12 hours of light. Plants watered weekly grew better than those watered daily or bi-weekly. Adding calcium chloride to the soil, up to 0.1 molar concentrations, stimulated plant growth; all concentrations of sodium chloride studied significantly reduced plant growth. In general, plants fertilized with 50 lbs per acre of N, P, NP, and NPK increased growth of E. lanata significantly more than treatments of K and PK. Apparently the soil contained enough K for good plant growth. A better stand was obtained when seed was planted with a range seeder on April 4 than when planted May 16. Stands were also better when seed was planted shallow on plowed soil than when planted deep; however, the deeper planting in sod produced better stands than the shallow planting.

The relative frequency of E. lanata in Rock Valley is about 2% (number of E. lanata plants per hectare was 52) (data of William Martin). It tends to grow well in poorly aerated and fine-textured soil. The almost pure stand of it shown in Figure 2 is in just such an area, and this behavior has been reported (Gates et al., 1956). E. lanata is in the foreground occupying the playa of a shallow drainage basin with a band of Artesmisia on the bajada above the E. lanata and Juniper trees growing above the Artemisia. It is tolerant of a slight amount of

Table 1. Mineral composition of leaves of *E. lanata* grown at the Nevada Test Site.

Location	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
			% of dry weight									ppm of dry weight						
Rock Valley	.34	.06	4.02	1.72	.53	.14	20	3	200	118	61	338	25	2.4	.5	1.4	118	21
Frenchman Flat	.28	.12	3.91	1.83	.58	.28	29	13	299	133	54	577	59	5.1	.5	1.1	95	27
Mercury Valley	.27	.11	3.86	1.79	.61	.16	19	10	238	110	54	387	26	7.1	.7	1.5	107	16
Pahute Mesa	.20	.06	3.17	1.46	.31	.37	16	34	445	91	104	746	68	1.1	T	4.0	62	51
Nye Canyon	.23	.10	4.41	1.32	.47	.24	16	8	513	100	43	612	40	1.3	T	1.0	49	40
Area 11	.20	.10	2.61	1.15	.49	.25	9	2	234	86	75	458	19	1.3	2.0	T	77	26

Table 2. Mineral composition of leaves of *E. lanata* grown in Yolo loam soil for 40 days at different root temperatures (seedlings 1 year old but cut back to crown before start of test).

Root temp. °C	Yield of shoot g/plant	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
				% of dry weight									ppm of dry weight						
16	6.81	.44	.04	4.88	2.17	.80	.36	171	18	434	333	158	806	140	.8	4.0	6.3	75	86
21	4.05	.62	.04	4.16	2.12	.82	.54	355	24	589	595	154	1034	184	.8	4.6	12.0	80	154
28	2.72	.64	.04	3.43	2.44	.83	.34	171	65	423	672	278	669	840	1.0	4.4	10.8	84	100

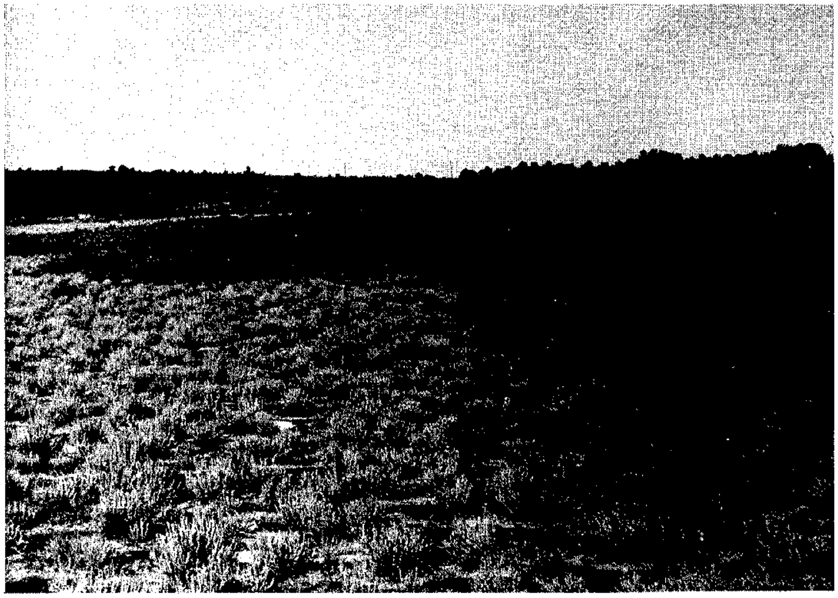


Figure 2. Pure stands of E. lanata often occupy the playas of shallow drainage basins in the Pahute Mesa area of the Nevada Test Site.

salinity, but appears to grow best without salinity. This shrub tends to retain foliage year round unless it is removed by strong wind action. It grows at elevations below 2,300 m at the Nevada Test Site.

A large number of E. lanata seedlings were present in the spring of 1969 at the Nevada Test Site following a large amount of rain in February. They occurred either alone in open areas or in existing shrub clumps. Similar effects have occurred in study plots given supplementary moisture by sprinkler-irrigation near Mercury, Nevada.

Experimental Results

Mineral composition of leaves of field-grown plants are in Table 1. Sodium contents were very low, even though the species is moderately tolerant of salt. Zinc contents were higher than those in samples from some other plant species growing in the same areas as were the iron and aluminum contents. Mineral analyses (Table 2) of E. lanata plants grown at different soil temperatures in Yolo loam in the glasshouse indicated that this species may accumulate very high zinc contents. Copper and titanium contents were high and increased with soil temperature; aluminum contents were high. Yields decreased greatly as soil temperatures increased. This species, like Grayia spinosa, seemed to prefer cool soil temperature and behaves more like the cold Great Basin Desert species. Gibberellic acid broke dormancy of E. lanata.

Further experiments studying the interactions of air and root temperatures on growth of E. lanata disclosed some interesting characteristic of this plant species (Figure 3). It grew equally as well at cool root temperature as it did at warm root temperature and cold air temperature. Poorest growth occurred when both air and root temperatures were either warm or cold. It appears that E. lanata can adapt to either warm or cold desert conditions which probably accounts for its wide-spread occurrence at various elevations in both the Mojave and Great Basin Deserts.

Samples of leaf and stem tissue taken from E. lanata in dormant and active growth seasons showed considerable disparity in some mineral contents; therefore, leaf samples were taken from the same shrubs at different intervals in

Table 3. Seasonal mineral contents of E. lanata in 1969.

Sampling date	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
	% of dry weight						ppm of dry weight											
							Leaf tissue											
11 February	.17	.014	1.23	1.96	.38	.33	58	34	901	53	85	732	40	1.3	3.7	T	54	13
17 March	.28	.022	2.29	1.65	.43	.34	47	6	969	74	53	805	60	1.3	2.5	1.0	42	11
4 April	.16	.063	3.54	1.44	.67	.27	43	9	774	67	68	792	36	T	4.1	2.9	43	13
21 May	.14	.026	2.66	.81	.38	.05	29	12	441	27	69	443	3	T	T	1.5	36	5
19 June	.08	.044	2.03	1.97	.63	.32	37	3	850	49	202	806	45	T	1.5	1.5	61	12
29 July	.04	.054	1.49	1.59	.43	.51	21	3	1312	28	259	1077	117	T	1.6	2.2	59	14
24 September	.06	.030	1.09	1.27	.27	.39	28	12	899	25	279	810	116	T	T	2.3	48	11
31 December	.19	.034	1.35	2.16	.51	.47	36	6	782	38	182	1544	126	0.9	2.5	T	57	27
							Stem tissue											
11 February	.04	.002	1.31	0.67	.14	.09	36	37	252	38	17	188	14	0.8	2.4	1.1	31	7
17 March	.03	.004	.86	.56	.14	.13	16	3	299	41	19	291	31	T	0.7	1.0	27	7
4 April	.07	.017	2.78	.66	.28	.08	18	6	393	42	19	323	8	T	T	T	32	11
21 May	.05	.008	2.38	.44	.17	.04	15	5	196	19	28	102	3	T	T	T	37	7
19 June	.04	.005	1.49	.73	.23	.05	26	37	382	22	18	146	3	T	T	T	45	9
29 July	.03	.004	1.62	.85	.21	.07	33	42	242	18	18	179	5	T	T	T	57	9
24 September	.02	.008	1.29	.92	.19	.07	35	37	335	33	18	233	7	T	1.2	T	45	8
31 December	.05	.004	1.59	.81	.16	.10	21	27	164	24	24	154	4	1.1	2.4	T	28	12

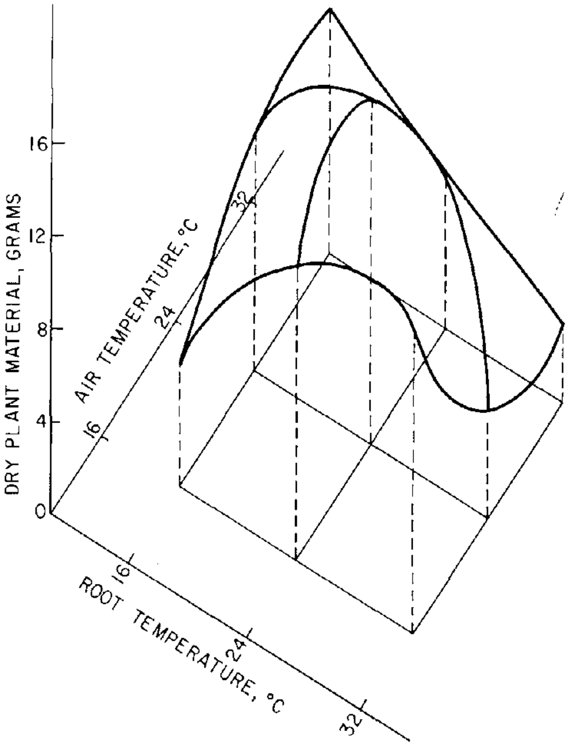


Figure 3. Growth response of E. lanata to variations in air and root temperatures.

1969 and analyzed by emission spectrograph. Results in Table 3 are of interest. Notably, the sodium content remained very low as did the phosphorus content. The potassium content was greatest during the period of active spring growth then decreased as the tissues matured. There was tendency for calcium to decrease in leaf tissues during the period of most active growth (April and May) and silicon tended to follow the same pattern. Boron and titanium accumulated in leaf tissues with increasing age. Zinc, copper, iron, manganese, and aluminum contents tended to decrease in both leaf and stem tissues during the period of greatest new foliage production in the late spring months which may be a reflection of carbohydrate dilution in these tissues. The iron and aluminum contents of E. lanata are among the highest observed in any of the different plant species we have studied at the Nevada Test Site.

Cuttings were easily rooted when dipped into Hormodin 2 powder and placed in vermiculite in a lathhouse (relatively cool) until rooted.

E. lanata plants were grown in solution at various sodium chloride and sulfate levels in a preliminary test of its salt tolerance and it proved to be rather intolerant of salt.

Summary

Eurotia lanata grows either in association with other shrub species or in pure stands. It tends to grow well in poorly aerated and fine-textured soils. It germinates readily in the field when soil moisture conditions are favorable. It prefers cool soil in the field and goes dormant as soil and air temperatures increase. This dormancy can be broken by soil applications of gibberellic acid. It tolerates moderate amounts of sodium, but leaves contain little of it. It is an accumulator of aluminum, copper, and zinc when available. Copper, titanium, and manganese contents of leaves increased greatly with increasing soil temperature. It accumulates high levels of iron and aluminum. Plants can be readily reproduced by cuttings and by seedlings.

CHARACTERISTICS OF *ARTEMISIA* SPECIES (SAGEBRUSH)

General Description

Beatley (1965, 1969) lists six species of *Artemisia* for the Nevada Test Site and nearby areas. These are *Artemisia arbuscula* Nutt. subsp. *nova* (A. Nels.) Ward; *Artemisia bigelovii* Grey in Torr.; *Artemisia dracunculus* L.; *Artemisia ludoviciana* Nutt. subsp. *incompta* (Nutt.) Keck; *Artemisia spinescens* D. C. Eat.; and *Artemisia tridentata* Nutt.

The *Artemisia* species are most pronounced in the Great Basin Desert of which Shreve and Wiggins (1964) state: "The vegetation of the Great Basin Desert is dominated by a small number of species of low shrubs, most of which are either wholly or partly deciduous. It is almost devoid of trees and also of shrubs with large evergreen leaves, and is poor in succulents and semisucculents. A distinctive feature of the vegetation is the predominence of communities which are very simple in composition or have as much as 95 per cent of their stand made up of a single species. The commonest dominants of these uniform communities are *Atriplex confertifolia*, *Artemisia tridentata*, *A. nova*, *Chrysothamnus puberulus*, and *Eurotia lanata*. Each of the communities is sharply confined to its particular site and type of soil, and in each of them the stature of the plants is determined by local conditions of water supply. In the simplicity of its vegetation and the small number of life forms it contains, the Great Basin Desert is distinctly of the cold northern type."

In studying sagebrush in Wyoming, Beetle (1960) observed that *A. tridentata* is found in a great variety of ecological sites, ranging from wet to dry, and on soils ranging from strongly alkaline to non-alkaline. Branson et al. (1970) reported that shale derived soil occupied by sagebrush in Montana had low soluble salt content, relatively high soluble sodium, and intermediate total soil moisture stress values. They further indicated that sagebrush has a narrow range of tolerance to total soil-moisture stress. Vest (1962) has reviewed earlier work pertinent to sagebrush tolerance of soil salinity and some other chemical properties. Billings (1950) reported a restriction of sagebrush from phosphorus-deficient soils in Nevada, indicating low tolerance for low levels of phosphorus. This sensitivity to low phosphorus was further borne out by the work of Wright (1963) and Wright and Mooney (1965) which indicates that low phosphorus content may account for the poor distribution of sagebrush on dolomitic soils.

Marda West (1969) recently reported a physiological ecology study of the characteristics of three species of *Artemisia* in the White Mountains of California. In this area *A. tridentata* occupies a climatic span from the desert to the subalpine (1,800 to 6,000 m) on the sandstone, granite and limestone soils. *A. arbuscula* ranges through the sub-alpine and alpine zones (3,050 to 3,900 m) on dolomite, sandstone and granitic soils. *A. nova* is restricted to limestone soils in the pinyon-juniper woodland between 2,100 and 2,900m. The high elevation *A. tridentata* and *A. arbuscula* shrubs had more efficient photosynthesis at lower temperatures; the lower elevation *A. nova* was more efficent at higher temperatures. *A. tridentata* is the more drought-tolerant species, whereas *A. nova* is the least tolerant of environmental drought. The capability of *A. tridentata* and *A. arbuscula* to undergo photosynthetic acclimation is considered to be a major factor in the survival of both species over a wide range of environmental conditions encountered in their natural range. Likewise, *A. nova* is restricted elevationally partly due to its inability to acclimate photosynthetically. Miss West further concluded that the correlated effects of metabolism, germination and growth, and water relationships probably all serve to limit the species elevationally in the White Mountains of California.

Passey and Hugie (1962) have described some relationships of *Artemisia* species to soil formation. They reported that *A. tridentata* stands are relatively dense on deeper-structured soils and there is a definite inhibition of grasses and annual plants in stands of *Artemisia* species. Whether or not allelopathy, as well as water relations, is involved is not well understood. The recent work of Muller (1966) shows some inhibitive effects of chemical substances derived from *Artemisia californica* and *Salvia leucophylla* on the growth of several different grasses. Range management methods of eradicating the *Artemisia* species do greatly increase the growth of grasses and herbaceous plants. Earlier work on these range management practices has been summarized by Pechanec et al. (1954). The revegetation of sagebrush areas destroyed by beta radiation in close-in fallout areas of nuclear cratering tests initially has come from grass species (Rhoads et al., 1967, 1969, 1970). *Artemisia* species are grazed to a limited extent, particularly if livestock have other sources of feed simultaneously. The rich spice flavor of sagebrush limits its acceptability to animals and, as mentioned earlier, the grazing potential of rangelands can be increased by its removal.

On the Nevada Test Site, a mosaic of *A. tridentata* and *A. arbuscula* subsp. *nova* begins at around 1,600 m and continues to the highest elevations. Both species occur commonly in nearly pure stands. *A. tridentata* is associated with relatively deep, sandy soils of valley bottoms, benchlands, and the flatter terrain of the uplands, as on the tops of mesas. *A. arbuscula* occupies the shallow, stony soils of the hill and mountain slopes and ridges. The boundaries between the two types are usually sharply defined (Beatley, 1965, 1969). The *Artemisia* species in general (not *A. spinescens*) are evergreen or nearly so even though they tend to abscise leaves in the fall. New inflorescences usually appear on these species in April and May and flowering, except with *A. spinescens*, usually occurs in early fall with seed maturing late in the fall.

Experimental Results

Our field and laboratory work with sagebrush has been focused on *A. tridentata*. Figure 1 shows a typical form of this shrub about 75 cm in height and 75 cm in width dimensions. The major portion of the root system of this plant is shown in Figure 2. These shrubs have dense root systems which tend to spread laterally in shallow soils or penetrate deeply into well structured soils. Goodwin (1956) reviewed earlier work on root systems of sagebrush species and reported on studies of rooting characteristics of seedlings and mature shrubs in shallow and deep soils.

The deeper soils occupied by *A. tridentata* are notably fertile and suitable for agricultural use when supplied with supplementary moisture (Fireman and Hayward, 1952). We found soil from underneath sagebrush shrubs to be of excellent quality for use as a potting soil for glasshouse experiments.

The root to shoot ratios of *A. tridentata* shrubs vary considerably, and appear to reflect local conditions of both soil structure and available moisture. Goodwin (1956) earlier observed tremendous variability of the morphology of the big sagebrush root system. Most of the above-ground biomass of mature shrubs is contributed by the heavy, gnarled stem wood. Leaves and inflorescences contribute a greater proportion of the biomass of young shrubs than they do in old, mature shrubs.

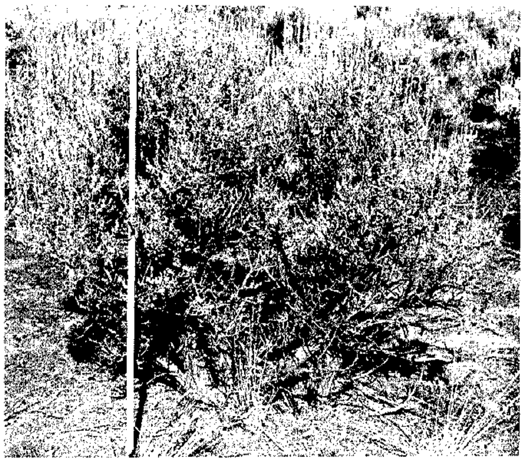


Figure 1. (left) Shrub form of mature A. tridentata at the Pahute Mesa study site.

Figure 2. (right) Exposed root system of the A. tridentata shrub shown in Figure 1.

Nitrogen fixation occurs in the roots of A. tridentata presumably through microbial endophyte association in root nodules. Farnsworth and Hammond (1968) found nitrogen fixing microorganisms in nodules on the roots of A. ludoviciana. This important life process of ecological significance is discussed in greater detail elsewhere in the section on nitrogen fixation in desert vegetation (see page 352).

The stems of old specimens of A. tridentata often appear to have split apart and allowed soil to work down around the root crown forcing the fractionated stems to move away from each other. In time this results in the appearance of a cluster of separate plants, but closer examination shows that these stem parts originally fit together. An interesting happening shed further light upon this curious stem fractionation process. In December of 1967 we staked out the shrub shown in Figure 3 and marked its mean height in order to determine the extent to which vertical growth might continue in successive years. We saw no marked change in height during 1968 and were surprised to find a decrease in height when we checked this shrub in May of 1969 (Figure 4).

Figure 3. (left) A. tridentata shrub staked out in December 1967 for continued observation of change in growth.

Figure 4. (right) Same shrub in Figure 3 photographed again in May 1969 after stem wood had split from heavy snow and ice packs allowing branches to settle to the ground.

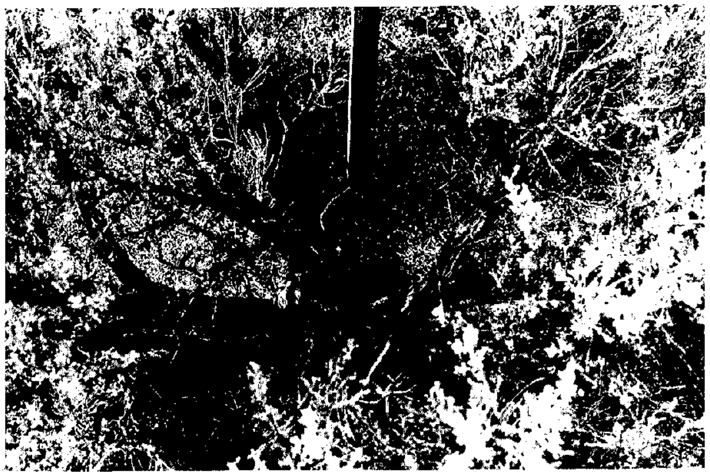
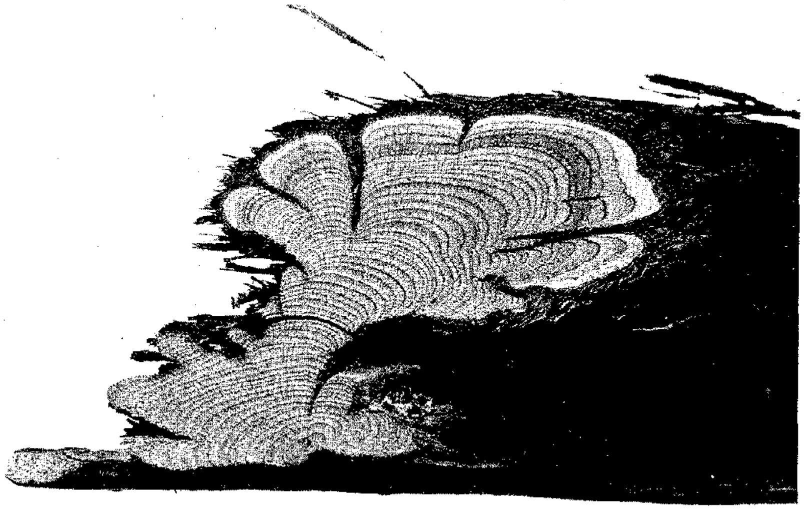


Figure 5. Close-up view looking down on the shrub shown in Figure 4 which shows how branches split apart from the weight of snow and ice packs.

Close examination disclosed that the weight of the heavy snow and ice pack from the severe storms which occurred in January and February of 1969 had split apart the main stem of the shrub, allowing its branches to settle toward the ground (Figure 5). Weather station records indicate that about 12.5 cm of precipitation occurred during these storms at this study site.

The manner in which stem wood became fractionated is further illustrated by Figure 6 which also shows the ring structure across an oblique cut through a branch. Note that the main cleavage initially appears to have occurred through the center of the stem. This stem section varied from 5 to 6 cm in width. If each ring represents 1-year's growth, the age of this shrub was around 60 years. Ferguson (1964) has reported on studies of annual rings in

Figure 6. An oblique cross section of a fractionated stem from a mature A. tridentata shrub showing the typical growth ring structure.



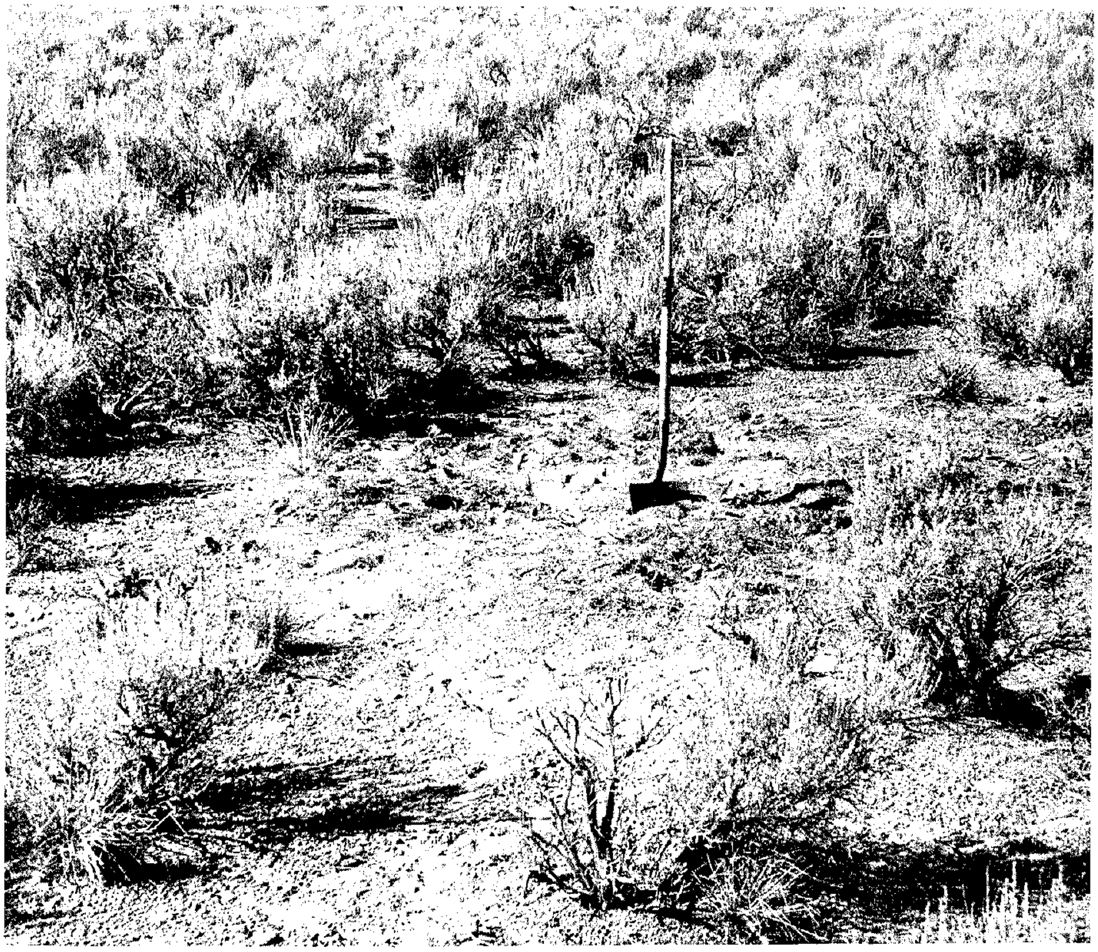


Figure 7. One of several 3 × 3 meter study plots denuded by removing shrubs, including roots.

big sagebrush (A. tridentata). Based upon the evidence from growth ring counts, the big sagebrush at the Nevada Test Site reaches relatively old ages from 50 to 100 years. About one-third of the specimens of A. tridentata at two study sites on Pahute Mesa were completely dead, many of which had not reached old age. Ring counts of stem wood sampled from representative shrubs which were not seriously decomposed varied from 22 to 87 rings and an average for 25 samples counted was 41 rings. If the number of new seedlings (less than 15 cm tall) present in the stands represents normal reseeding, the proportion of new seedlings to mature shrubs and dead specimens indicates that the average life span of A. tridentata at these sites may be no more than about 30 years.

Reseeding occurred rapidly in plots that had been denuded by removing shrubs, including roots. The illustrations in Figures 7 and 8 show an example of reseeding that occurred during the three year period following removal of shrubs. We counted 53 seedlings in this 3 × 3 m study plot after the first year. There were 27 seedlings in the plot two years after shrub removal and 19 remained the third year. If normal density were restored to this particular plot, five to seven seedlings should survive to maturity. Competition for moisture is not the only factor preventing seedling survival. In October of the third year (1970) after shrubs had been removed, we visited these plots

Figure 8. Closer view of the plot in Figure 7 showing new seedling development during the 3-year period following denudation.

Figure 9. View of the study plot shown in Figure 7 and 8 showing the decimation of seedlings by grazing rabbits.

and found that rabbits had seriously pruned the foliage from most of the seedlings (Figure 9). Apparently the young stem tips are preferred eating by the animal because leaves and inflorescences were left uneaten beside the pruned seedlings (Figure 10). This pruning by rabbits also occurred on seedlings elsewhere than in the denuded plots and in many cases the young stem wood was chewed right down to the root crown.

Less than half the normal rainfall occurred during the winter and spring preceding the 1970 growing season. New primary productivity on A. tridentata shrubs was noticably poor as was inflorescence development. This drought condition probably contributed to animal predation on seedlings in 1970 in that there was no evidence of such predation in 1967 to 1969. The extent to which these severely pruned seedlings can continue to survive is of continuing interest to us because damage to seedlings from grazing animals may be a major factor contributing to the paucity of native shrub revegetation in disturbed areas of the Nevada Test Site. There are a number of denuded areas varying from a few square meters to several square kilometers in size in which there has been virtually no revegetation by the native shrub species after nearly two decades. Seedlings do germinate in these areas but virtually none have survived. We presume that one dominant factor involved is the lack of sufficient moisture during the period necessary for seedlings to become established. We see much evidence, however, of damage to seedlings by animals which we

Figure 10. Close-up view of A. tridentata seedlings in study plot heavily pruned by rabbits which indicates that young stems were preferred in their diet over leaves and inflorescences which have been left on the ground. Note rabbit droppings near plant.

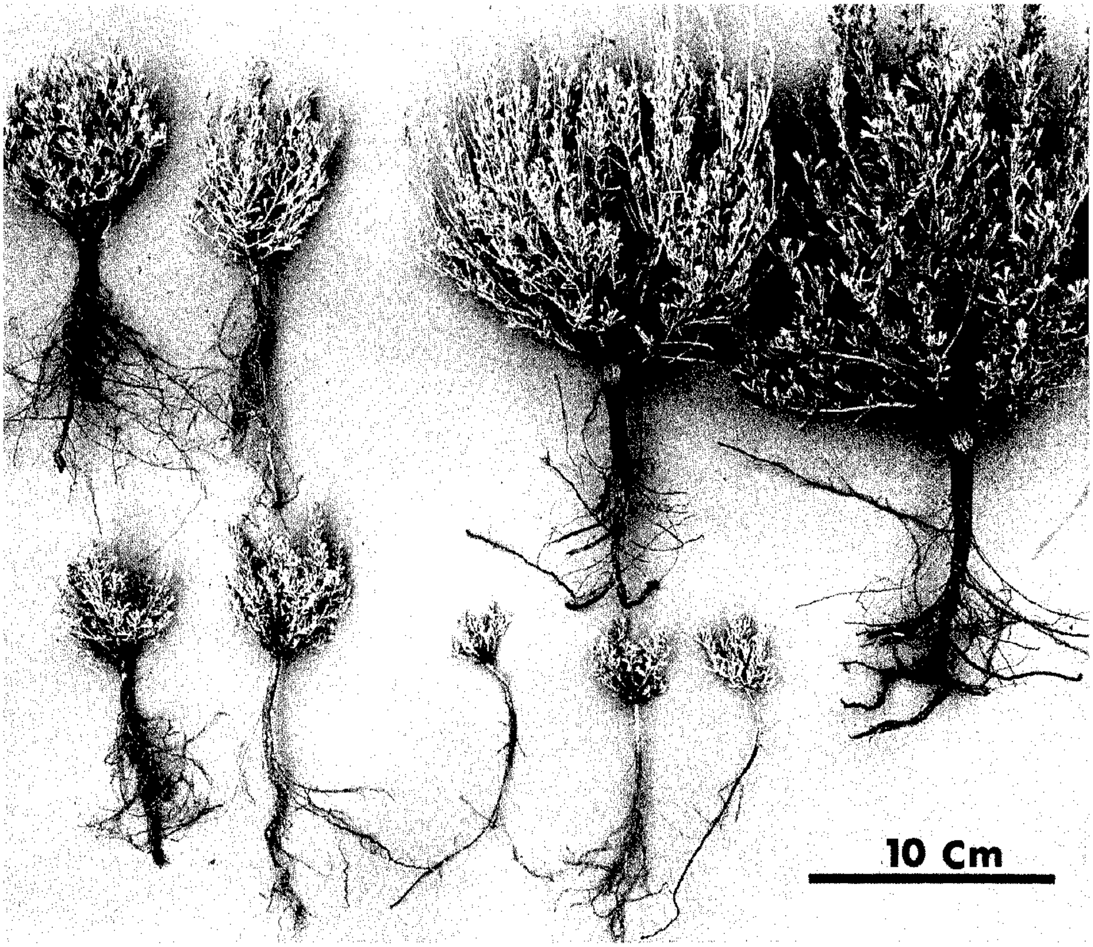


Figure 11. Examples of A. tridentata seedlings excavated from a disturbed site which show the influence of available soil moisture. All seedlings had three growth rings.

believe is of considerable ecological significance. The small-mammal population of these areas is relatively high and stable because of the sustaining food supply from good stands of winter annuals and grasses which have become established on these disturbed sites. The extent to which small mammals may decimate seedling populations was clearly evident from a study in which an attempt was made to transplant seedlings and rooted cuttings of several shrub species in a denuded area. One hundred 1- to 3-year old plants were transplanted in a grid 10 m apart in October 1970. Within two weeks all plants had been either consumed or severely pruned. The presence of fresh rabbit droppings among the transplant sites showed that rabbits had been eating in the area, and we suspect that small rodents also may have been active participants. The shrub species involved were Artemisia tridentata, Larrea divaricata, Lycium andersonii, Lycium pallidum, Ephedra viridis, Atriplex canescens, Atriplex confertifolia, Yucca brevifolia and Yucca schidigera.

The influence of available soil moisture on seedling development is illustrated in Figure 11. Seedlings ranging from 5 to 20 cm in height and from 5 to 20 cm in diameter were excavated from alongside a bladed roadway. At first we thought that the different sized seedlings at this particular site might represent different aged plants; however, subsequent dissection disclosed that each of these seedlings had three growth rings. Further study of this site disclosed that seedlings growing near or in local moisture catchments were larger than seedlings growing on well-drained slopes. The seedling population at this site apparently resulted from seed germination in the spring of 1967. Annual rainfall measured at the nearest A. R. L. Meteorological Station for the three years following germination was 26.7 (1967), 18.7 (1968), and 23.5 (1969) cm.

A. tridentata is the only sagebrush species which we have worked with in the laboratory. Seeds germinate easily and cuttings are also easy to root, especially when succulent, vigorous material from young plants is used and when treated with 0.3 per cent IBA and then rooted in a mist house.

One-month-old seedlings were transplanted along the edge of glass-fronted boxes of soil which were 50 cm deep. A cover over the glass front was removed periodically to observe vertical penetration of the roots. Normally there was the formation of one long taproot; however, we noted that when the taproot was injured in transplanting, a root system of several nearly equal branches was formed. The taproot of one seedling elongated to 46 cm from an initial length of 2 cm in 16 days. The work of Goodwin (1956) on seed germination and root development of *A. tridentata* is pertinent. Goodwin observed that germination occurred readily without pretreatment but was increased by moist stratification at 2°C. Temperatures above 25°C inhibited germination. Germination occurred at temperatures of 5 and 7°C. The most uniform and highest percentage germination was obtained at 17 and 19°C under normal daylight. Field germination began the first week in February and ceased in April at his study site located near Clarkston, Washington. Goodwin's studies further showed that the root systems of seedlings continued to develop even though the air temperature was below freezing. Aerial growth of seedlings was not noticable until the air temperature began a steady climb. Root systems were influenced by soil structure. On deep well-aerated soil, a taproot with few lateral roots developed. A root system of many widely branching laterals without the dominant taproot developed on shallow soil containing hardpan. Our observations at the Pahute Mesa study sites essentially agree with these earlier findings reported by Goodwin.

A. tridentata seedlings grew poorly in soil at 35°C (Table 1). They grew much better at 13 and 22°C, but growth was best at 22°C. In a second experi-

Table 1. Effect of root temperatures on growth and mineral composition of *A. tridentata* seedlings in Yolo loam soil for 2 months.

Soil temp. °C	Yield mg/ plant	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Mo	Sr	Ba
		% of dry weight					ppm of dry weight							
First experiment (whole plant)														
13	2740	0.50	0.20	2.87	0.70	0.27	63	42	894	382	250	4.4	27	78
22	3430	0.50	0.15	2.91	0.59	0.26	87	54	681	408	134	5.2	22	66
35	1110	0.69	0.20	3.02	0.49	0.26	61	34	1182	269	149	4.7	23	88
Second experiment (leaves only)														
16	2330	0.43	0.04	3.90	1.77	0.28	14	15	210	99	91	4.8	54	48
21	2650	0.39	0.04	5.15	1.74	0.34	21	14	206	100	87	4.0	60	58
28	930	0.52	0.08	2.97	2.97	0.52	10	14	520	126	156	1.4	77	115

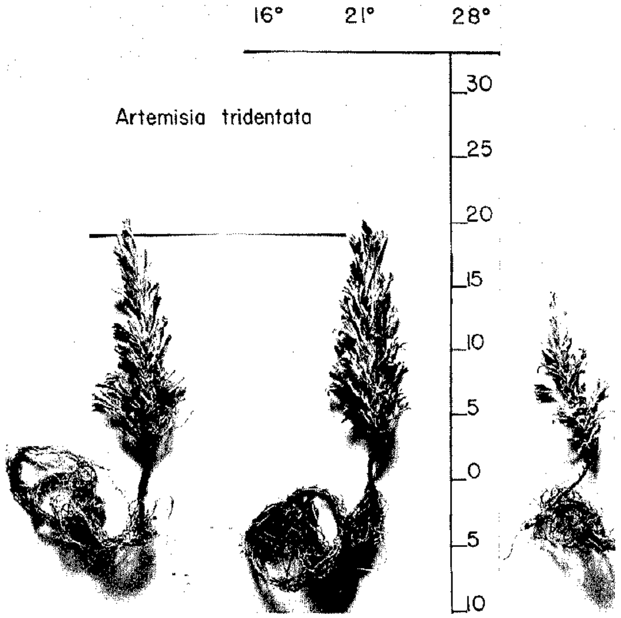


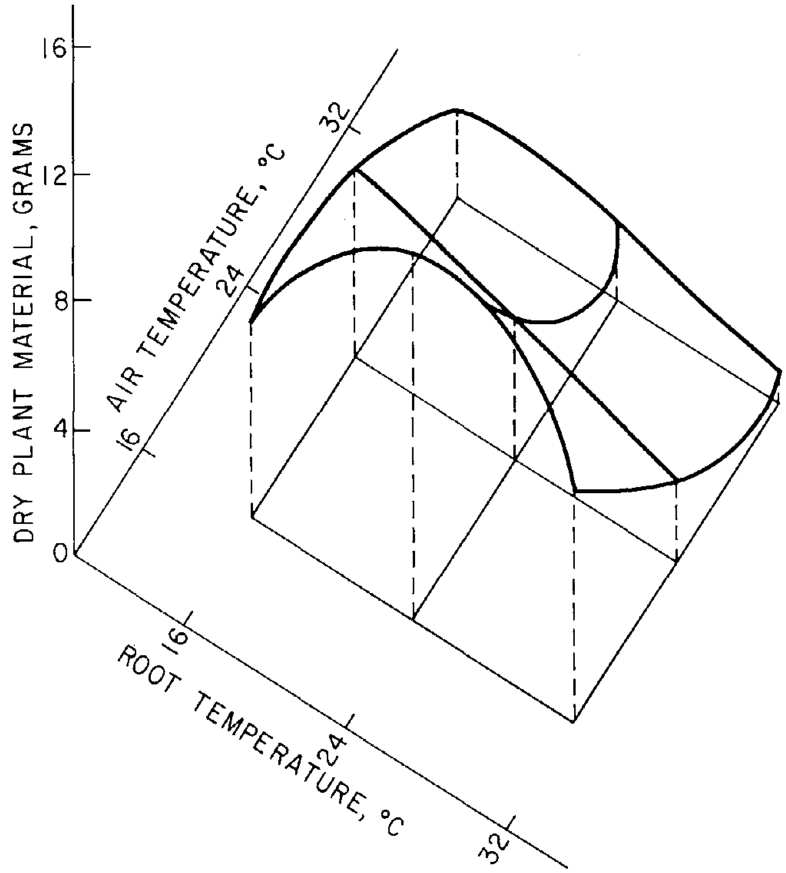
Figure 12. Response of A. tridentata grown at different root temperatures for 60 days (scale is cm.).

ment rooted cuttings definitely preferred cool soil temperature to warm temperature (Figure 12). Growth at root temperatures of 16 and 21°C was much better than at 28°C. In both of these experiments the air temperature was that of the glasshouse which varied from 25 to 28°C. In a third experiment both air and root temperatures were varied. Figure 13 shows the growth response of rooted cuttings from this test in which A. tridentata again showed a decided preference for cool soil and for cool air temperature, to an almost equal extent. Optimum growth occurred at 24°C root temperature and 16°C air temperature. Yields and mineral analyses for the first two experiments are listed in Table 1. These cooler temperatures are more typical of the ambient and root temperatures to which shrubs native to the Great Basin Desert are subjected during their peak growth period in late spring. The high temperatures are more typical of the conditions which shrubs of the Mojave Desert should encounter during peak growth season. We believe that this preference for cooler air and root temperatures is one reason why A. tridentata grows abundantly at elevations of 1800 meters and above but not lower than about 1500 meters at the Nevada Test Site (Wallace et al., 1970).

A. tridentata seedlings and rooted cuttings are sensitive to chlorides in soils and also in nutrient solutions. Figures 14 and 15 show the growth response to levels of 80, 180, and 280 me per liter compared to standard Hoagland solution when supplied as $CaCl_2$ or NaCl. Poorest growth occurred when supplied as $CaCl_2$. It would further appear that this species is sensitive to chloride rather than sodium from the results of an experiment which showed a rather high tolerance of sodium applied to nutrient solution as Na_2SO_4 (Figure 16). The presence of 280 me Na_2SO_4 per liter of nutrient solution was needed to markedly inhibit growth. The growth period on these different salt treatments was 60 days. Several investigators have reported on the sensitivity of sagebrush species to high salt concentrations and chloride sensitivity could contribute to the factors involved in the sharp demarcation lines in some ecotones between A. tridentata and other shrub species more tolerant of chlorides.

A. tridentata is found growing on calcareous and non-calcareous soils. At the Nevada Test Site this species grows abundantly on volcanic derived soils which are high in calcium. The necessity for high calcium for healthy growth was demonstrated in nutrient culture experiments where poor growth occurred when the calcium level was reduced to the range of 10^{-4}N Ca^{++} (Figure 17). It does appear, however, that A. tridentata is sensitive to soil pH and may grow better under neutral or slightly acidic conditions. We observed that this species grew better under these conditions in 90-day tests where Yolo loam soil had been amended with either 10 per cent $CaCO_3$ or 2 per cent sulfur. Yolo loam is one of the fertile agricultural soils of California with relatively

Figure 13. Dry weight yields of A. tridentata grown for 60 days at different air and soil temperatures.



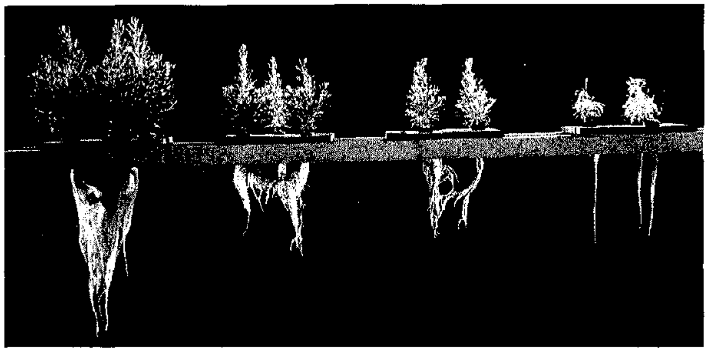


Figure 14. (top) Response of A. tridentata cuttings grown 60 days on Hoagland solution and $CaCl_2$ treatments of 80, 180, and 280 me. per liter.

Figure 15. (center) Response of A. tridentata cuttings grown 60 days on Hoagland solution and NaCl treatments of 80, 180, and 280 me. per liter.

Figure 16. (bottom) Response of A. tridentata cuttings grown 60 days on Hoagland solution and Na_2SO_4 treatments of 80, 180, and 280 me. per liter.

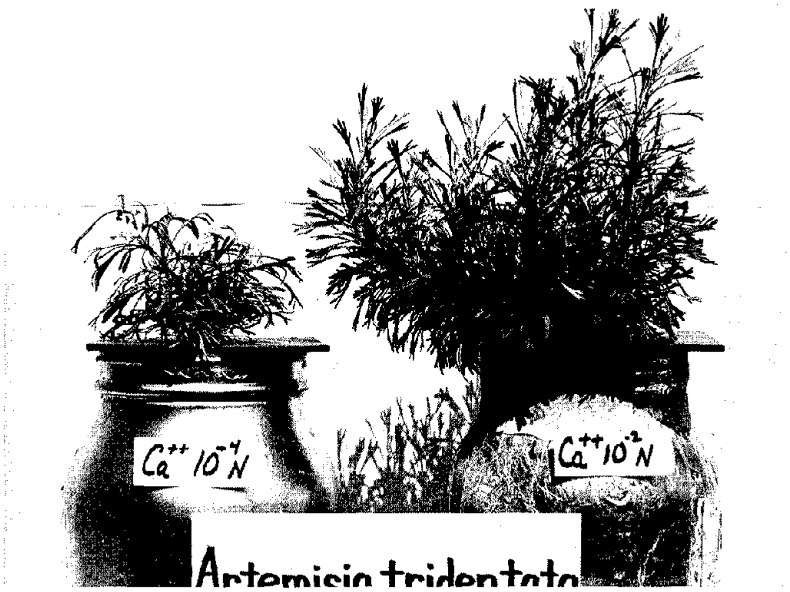
high levels of calcium and near neutral pH. Yield data and mineral composition of plants from this experiment are shown in Table 2. Iron, manganese, cobalt, zinc, and molybdenum contents were related to soil pH in that molybdenum showed a positive relationship and the others a negative relationship.

Table 2. Shoot yields and mineral composition on the dry weight basis of leaves of A. tridentata grown in Yolo loam soil with and without excess $CaCO_3$ and sulfur.

Measurement*	Unit	$CaCO_3$ (pH 7.5)	Control (pH 6.0)	Sulfur (pH 4.2)
Leaf wt	g/plant	2.92	4.06	8.20
Stem wt	g/plant	1.22	1.64	2.30
Ca	%	0.81	0.67	0.54
K	%	2.27	2.44	3.16
Mg	%	0.21	0.19	0.24
Na	%	0.09	0.03	0.09
P	%	0.34	0.42	0.53
B	ppm	62	58	45
Cu	ppm	40	38	37
Fe	ppm	140	112	315
Mn	ppm	95	154	551
Co	ppm	1.4	2.1	8.5
Mo	ppm	6.2	2.2	2.5
Zn	ppm	40	100	129

*Mean of 3 replicates.

Figure 17. Growth response of A. tridentata to calcium levels in nutrient solution.



A. tridentata seedlings and cuttings may be sensitive to air pollution in the Los Angeles area. Plants growing outdoors and in the glasshouse without carbon-filtered air often have browned leaves indicative of air pollution injury. On the other hand, plants grown in growth chambers and in glasshouses with carbon filter protection have not shown this damage.

The *A. tridentata* shrub is relatively sensitive to ionizing radiation. It is one of the most sensitive shrubs to fallout beta and gamma radiation in areas of fallout deposition downwind from nuclear testing events (Rhoads et al., 1967, 1969, 1970). This species had a relatively high nuclear volume (487 μ^3). Studies with the 10,000 curie ^{60}Co gamma radiation source at this laboratory showed that acute radiation levels of less than 2,000 R can inhibit growth, and levels above 3,000 R can be lethal. An example is illustrated by Figure 18 wherein acute irradiation levels greater than 3,000 R were lethal to one-year-old specimens within 90 days after exposure.

Table 3. Mineral composition of field grown *A. tridentata* at Pahute Mesa on the dry weight basis.

	Unit	Stems		Leaves	
P	%	0.13	.16	0.17	.29
Na	ppm	132	624	362	584
K	%	2.32	2.28	1.78	2.71
Ca	%	0.60	0.43	0.89	0.96
Mg	%	0.11	0.20	0.15	0.27
Zn	ppm	12	10	25	18
Cu	ppm	14	12	14	13
Fe	ppm	294	364	390	376
Mn	ppm	47	75	95	128
B	ppm	21	54	37	74
Ti	ppm	37	23	47	21
Al	ppm	446	352	619	377
Mo	ppm	1.0	1.0	0.8	2.7
Co	ppm	0.5	2.3	0.5	2.6
Ni	ppm	2	4	5	11
Sr	ppm	47	63	42	72
Ba	ppm	19	38	25	26
Si	%	0.23	0.32	0.40	0.26

The mineral composition of samples from *A. tridentata* growing on Pahute Mesa is shown in Table 3. The two examples given are typical of the mineral elements generally found in leaf and stem tissues of this species.

Summary

The *Artemisia* species in general belong to the Great Basin Desert, and our soil temperature studies indicate that *A. tridentata* prefers cool soil temperatures (13 to 24°C) to hot soil (28 to 35°C). Optimum growth was obtained under controlled air and root temperature conditions of 24°C root temperature and 16°C air temperature. *A. tridentata* seeds readily germinate and under glasshouse conditions the roots of seedlings elongate at the rate of about 2.5 cm per day. Stem cuttings were easily rooted. *A. tridentata* in our Nevada Test Site study areas apparently live an average of about 30 years, but some

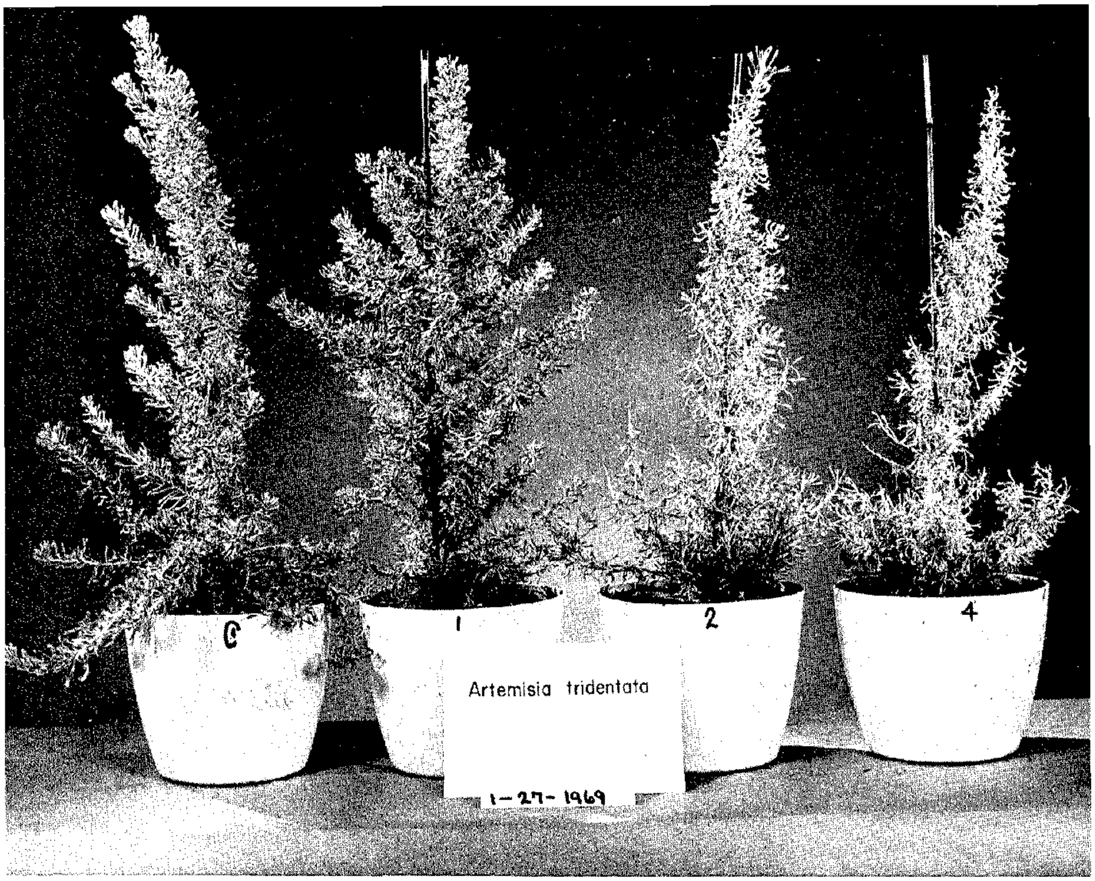


Figure 18. Acute irradiation levels greater than 3,000 R gamma were lethal to 1-year old A. tridentata shrubs within 90 days after exposure. (treatments, left to right, 0, 1, 2, 4 kR)

individuals do live much longer, especially under optimum edaphic and moisture conditions. About one-third of the plants in the stand were dead but there are sufficient new seedlings present in the area to replace the old stand in 20 to 30 years if the same rate of new seedlings is maintained each year. Rabbits graze on new A. tridentata seedlings and this may be an important factor influencing seedling survival. Stands of A. tridentata use soil moisture sufficiently to curtail the growth of grasses. In areas in which the shrubs had been destroyed by irradiation from fallout debris, the first stage of revegetation was from grasses. However, new seedling development has occurred in these areas in more than sufficient amounts to reestablish the original stands of A. tridentata. Possibilities of allelopathy between the species present is of continued interest to us. A. tridentata appears to be sensitive to chlorides and to changes in soil pH. It is commonly found growing on calcareous soils, yet it grows well on non-calcareous soil. Low calcium levels of about $10^{-4}\underline{N}$ in nutrient solution inhibited its growth. Field grown A. tridentata absorbs little sodium and it generally has lower phosphorus than many other shrub species.

CHARACTERISTICS OF EPHEDRA SPECIES (MORMON TEA)

Four species of Ephedra are present at the Nevada Test Site (Figures 1-4) (Beatley, 1965, 1969). Ephedra funerea Cov. & Mort., Ephedra nevadensis Wats., and Ephedra torreyana Wats. are common in the Mojave Desert portion of the Nevada Test Site. Ephedra viridis Cov. is common in the Great Basin portion of the Nevada Test Site.

Two of these are described by Shreve and Wiggins (1964).

Ephedra nevadensis S. Wats., Proc. Amer. Acad. 14:298, 1879.

> Erect, pale green or glaucous shrub 5 - 12 dm high with spreading, slightly scabrous, more or less flexuous branches; leaf scales in twos, 2 - 6 mm long, sheathing to about middle, obtuse to acute at apex, mostly deciduous in age; staminate cones sessile or short-pedunculate, with 4 - 9 pairs of obovate bracts 2 - 3 mm wide, 3 - 4 mm long; ovulate cones subglobose, 5 - 11 mm long on peduncles 1 - 50 mm long, bracts binate, round-ovate, in 3 - 5 whorls, firm, scarious on margins, sessile; seeds 1 - 2 in a cone, 6 - 9 mm long, 2 - 4 mm wide, exserted, smooth, trigonous, when 2 in a cone, with flattish face and strongly convex or carinate back.
>
> Arid hillsides and plains, Upper and Lower Sonoran Zones, Mojave Desert to southern Utah, south into Sonora and Baja California.

Ephedra viridis Coville, Contr. U.S. Nat. Herb. 4:220, 1893.

> Erect, rigidly branched shrub 5 - 12 dm tall with bright green or yellow-green branches 2 - 3 mm in diameter, their tips obtuse; leaves in pairs, 1.5 - 4 mm long, sharp-tipped, connate from one-third to three-fourths their length, deciduous but leaving persistent brown bases; staminate cones obovate, 5 - 7 mm long, sessile, with 6 - 10 pairs of ovate, yellow or slightly roseate and membranous bracts 2 - 3 mm broad, 2 - 4 mm long; ovulate cones obovate, 6 - 10 mm long, sessile or short-pedunculate, with 4 - 8 pairs of ovate branches 2 - 4 mm wide, 4 - 7 mm long; seeds trigonous, smooth or faintly striate, brownish, 5 - 8 mm long, 1 - 2 mm longer than bracts.
>
> Rocky hillsides, mesas, and washes, Lower Sonoran Zone to Transition Zone, eastern Ventura County, California, to western Colorado, south into Arizona and the Colorado Desert.

Benson and Darrow (1954) gives the following description for Ephedra torreyana:

> Ephedra torreyana S. Wats. Torrey Ephedra; Mormon Tea. (1) Scalelike leaves of the stem in 3's, 1/6 to 1/8 inch long; (2) seed roughened by short, narrow, crosswise ridges, beaked, the narrow beak as long as the body, wrapped in scales; (3) scales of the cones yellow on the thin, membranous outer parts, pinkish to reddish tan in the centers, the upper scales of the ovulate cones stalked. Branches rather large, the bulk of the twigs about 2 mm in diameter, green or yellow-green, perhaps sometimes glaucous; leaves with the apices recurved in age, 3 - 4 mm long, brown with the edges light, thin, and membranous; staminate cones nearly spherical or ovoid, about 5 - 7 mm long, the scales nearly circular, 2 - 3 mm long, stalks of the individual

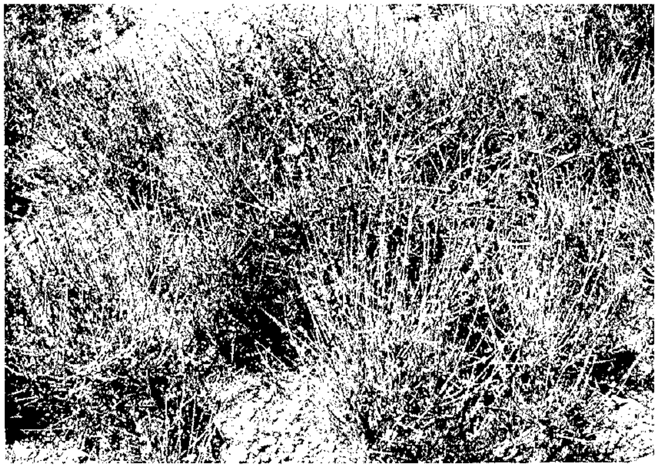


Figure 1. E. nevadensis shrub form common in the Mojave Desert portion of the Nevada Test Site.

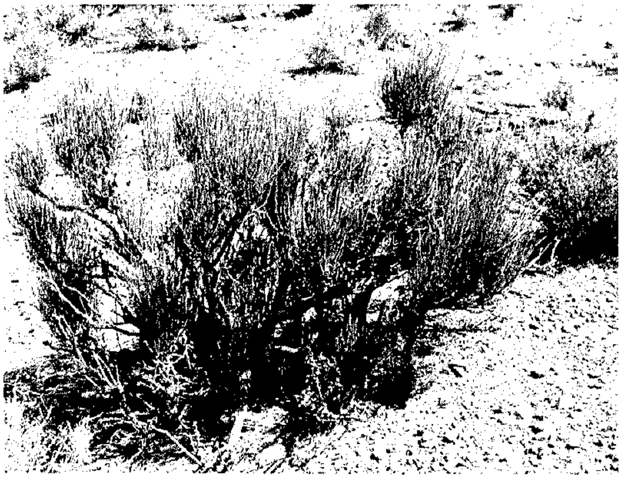


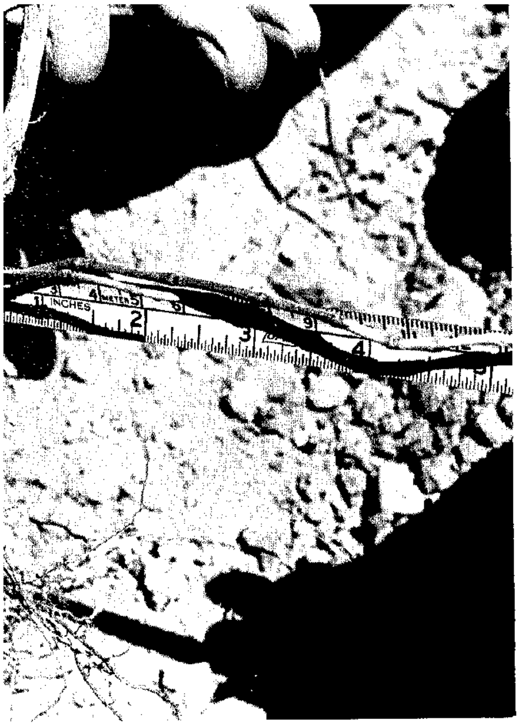
Figure 2. E. viridis shrub form common in the Great Basin Desert portion of the Nevada Test Site.

Figure 3. E. funerea shrub form in the Mojave Desert portion of the Nevada Test Site.

Figure 4. E. torreyana shrubform at the Nevada Test Site.

Figure 5. Staminate (male) cones on E. nevadensis growing at the Nevada Test Site.

Figure 6. Ovulate (female) cones on E. nevadensis growing at the Nevada Test Site.



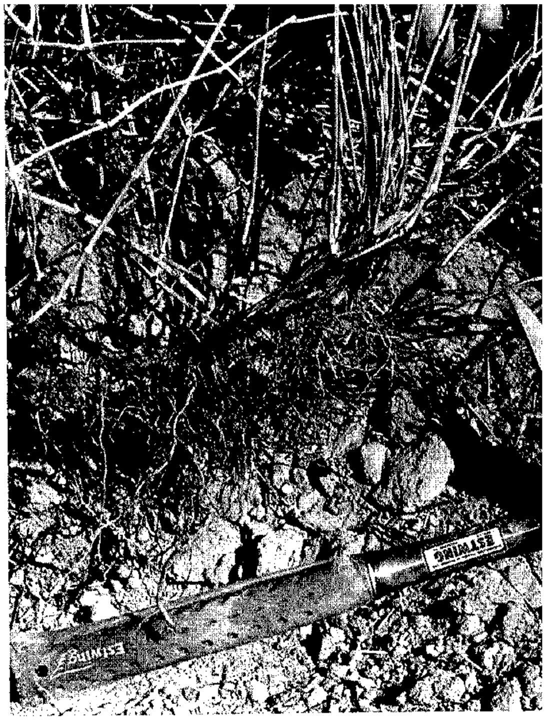


Figure 7. (left) New stolons produced on *E. nevadensis* growing in Rock Valley.

Figure 8. (right) Above-ground shoots of *E. nevadensis* colonies joined together by a complex network of rooted stolons.

Figure 9. *E. nevadensis* usually does not produce underground stolons when branches remain uncovered by wind-blown materials.

Table 1. Mineral contents of Ephedra species from study area at the Nevada Test Site.

Material and sample site	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Co	Ni	Mo	Sr	Ba
	% of dry weight						ppm of dry weight											
E. nevadensis																		
Rock Valley - new shoot	.23	.012	2.73	.61	.23	.11	27	9	325	41	55	378	7	T	T	T	76	11
Rock Valley - old shoot	.17	.030	.97	1.78	.33	.09	15	12	133	113	18	138	4	1	7	2	101	24
Mercury - new shoot	.31	.071	2.21	.77	.24	.04	27	17	153	13	24	127	2	T	T	T	51	24
Mercury - old shoot	.11	.013	.62	3.05	.44	.09	26	14	159	122	10	157	10	1	2	1	122	21
E. funerea																		
Mercury A - new shoot	.21	011	2.79	1.07	.27	.07	15	4	170	27	14	214	4	T	T	T	138	25
Mercury A - old shoot	.09	.032	.47	3.28	.27	.07	33	13	126	39	12	188	9	2	4	2	75	13
Mercury B - new shoot	.15	019	1.57	1.56	.31	.06	11	6	105	81	12	152	3	T	T	1	137	32
Mercury B - old shoot	.07	064	.38	1.64	25	.14	16	22	127	38	14	250	15	T	T	T	125	32
E. viridis																		
Area 20 - new shoot	.16	.039	2.34	.66	.27	.10	17	4	141	62	18	165	6	2	10	4	121	73
Area 20 - old shoot	.15	023	.50	2.72	.25	11	17	4	112	70	15	120	4	4	12	4	132	74
40-mi. Canyon - new shoot	.39	.023	3.03	.36	.22	.04	49	10	109	32	20	56	4	2	7	2	61	11
40-mi. Canyon - old shoot	.14	.046	.67	2.27	.40	.15	23	5	141	115	16	186	7	3	9	4	110	26
Yucca Mtn. - new shoot	.28	.008	2.59	.61	.20	.03	4	11	102	49	29	29	6	6	10	2	72	3
Yucca Mtn. - old shoot	.16	.025	.92	3.19	.24	.12	—	2	74	86	17	85	4	3	10	4	78	4
E. torreyana																		
Mercury - new shoot	.31	.026	1.82	0.76	.22	.04	15	5	88	43	28	44	2	5	4	1	127	17
Mercuty - old shoot	.12	.043	.45	2.34	.47	.12	7	3	136	91	21	112	5	2	2	2	151	21

anthers 0.3 - 0.5 mm long; ovulate cones not stalked, 10 - 12 mm long, the scales in many cycles of three, conspicuously membranous except in the centers, the blades 6 - 8 mm long, 7 - 9 mm broad, the stalks of the upper ones about 2 mm long; seed obscured by the scales, light colored, the body narrowly ovoid, 4 - 5 mm long, the beak or attenuation about the same length.

Sandy or gravelly plains and mesas in the sagebrush and creosote-bush deserts at 2,000 or commonly 4,000 to 6,000 feet elevation. Southern Nevada, nearly reaching the California border in Nye and Clark counties; central and southern Utah; southwestern Colorado; Arizona from northern Mohave County southeastward to northern Yavapai County and eastward along the Colorado and Little Colorado River drainages; New Mexico on the San Juan River and the Rio Grande drainages from Santa Fe southward; western Texas, Chihuahua, Mexico.

Munz (1959) gives the following description of *Ephedra funèrea*:

> *E. funèrea* Cov. & Mort. [*E. californica* var. *f.* L. Benson.] Erect, 0.3 - 1.5 m high, with stiff hard branches to 3.5 mm thick and internodes 2 - 6 cm long, pale, gray-green, glaucous, slightly roughened; lvs in 3's, 3 - 6 mm long; ♂ cones elongate-elliptic, 5 - 8 mm long, with 6 - 9 whorls of 3 bracts, these ovate, 3 - 4 mm long, membranaceous, yellowish; ♀ cones lance-obovate, 8 - 13 mm long, the bracts in 6 - 9 whorls, obovate, 4 - 8 mm long, yellow-translucent except for the green cent. part; seeds mostly 1, tetragonal, pale green to light brown, 6 - 9 mm long, smooth to scabrous.—At ca. 2000-5000 ft.; Creosote Bush Scrub; Death V. region, sw. Nev. March-April.

Ephedra is dioecious. It grows slowly and flowers irregularly. Its phenology is very dependent upon seasonal soil moisture conditions. In some years it grows extremely little and may not produce flowers and fruits in some years. The staminate (male) cones and ovulate (female) cones are produced in the springtime (Benson and Darrow, 1954) (Figures 5 and 6).

The species *E. nevadensis* is of particular interest in our study area in that it tends to produce clumps or "colonies" of shrubs originating from a host plant through underground stolon production, as is illustrated in Figure 7. Upon excavating a colony of *E. nevadensis*, one finds the above-ground shoots and branches joined together by a complex network of rooted stolons (Figure 8). Exceptions to this do occur, and it appears that stolon production is associated with the covering of branches by wind-blown sand and silt deposits that accumulate around the base of the shrubs. When a shrub is growing on terrain that is not conducive to the accumulation of wind-blown materials it usually does not show stolon formation (Figure 9).

Experimental Results

Before 1969 we were unable to collect seed in the field, but a commercial source of *E. viridis* germinated readily and specimens are available and growing in Yolo loam soil. Tests on *E. nevadensis* seed collected in Rock Valley in 1969 resulted in about 3% germination.

Most cuttings from field collections of different *Ephedra* species did not root under several methods of vegetative propagation, and those few which did root did not survive on transplanting. A large supply of cuttings was prepared, however, from the glasshouse-grown seedling stock of *E. viridis* and *E. nevadensis*.

Table 2. Seasonal change in mineral contents of *E. nevadensis* shoots. Samples were removed periodically from the same shrubs.

Sampling date	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Sr	Ba
1969			% of dry weight							ppm of dry weight				
11 February	.06	.003	.25	2.43	.18	.04	23	14	101	77	14	82	82	15
17 March	.09	.007	.31	2.21	.30	.07	19	10	142	136	12	134	97	24
4 April	.12	.012	.86	2.65	.34	.12	17	5	143	149	22	167	67	30
21 May	.08	.007	1.80	1.02	.17	.05	20	20	186	13	18	145	50	11
19 June	.08	.006	2.26	1.41	.20	.04	21	14	161	17	12	149	66	12
29 July	.05	.008	1.45	1.72	.18	.05	24	12	248	26	9	184	91	13
24 September	.04	.007	.91	2.37	.21	.10	22	19	240	38	10	188	96	18
31 December	.07	.009	.61	2.37	.19	.11	27	14	121	47	16	152	52	33

Some specimens of *E. nevadensis* have been bare-rooted in the field and brought to the laboratory for study. These have grown successfully.

Cuttings of *E. viridis* grown at different soil temperature for 60 days grew somewhat better at 20°C than at 16 or 28°C. The mean dry weight of shoots were 1.86, 1.29, and 1.26 g, respectively. This indicates that the species is a representative of the cool or intermediate desert.

Ephedra is extremely sensitive to ionizing radiation (Rhoads et al., 1969). In 1969, after 5 years of a chronic exposure to radiation from a 33,600 curie ^{137}Cs source (French et al., 1967; French, 1969; Turner and Lannom, 1968), vegetative growth and fruiting of *E. nevadensis* was greatly inhibited (see page 11). This result was of great interest in that for 4 years of the study no definite effects from the radiation were apparent, although suggestions of effects were noted (French, 1969). Additional experiments with *E. viridis* cuttings exposed to our laboratory ^{60}Co irradiation source showed the LD$_{100}$ dosage from acute exposure to be 3kR. The nuclear volume of *Ephedra* species is relatively large. Rhoads et al. (1969) reported nuclear volumes of 677 and 579 cubic microns for female and male *E. nevadensis*, respectively, and 631 cubic microns for *E. viridis* (sex not determined).

The mineral composition data in Table 1 indicate that the *Ephedra* species shoots are generally low in sodium and phosphorus. Analyses of new shoot tissues and tissues older than one year showed an inversion of the potassium and calcium contents of shoots in each of the four species examined; i.e., new shoots have high potassium and low calcium contents, and old shoots have high calcium and low potassium contents. Upon observing this, we periodically removed new shoot samples from the same tagged *E. nevadensis* shrubs for mineral analysis. Results in Table 2 show that the potassium content is low in new emerging shoots and increases as the new shoots mature. It subsequently decreases with age. On the other hand, the calcium content is high in new shoots and decreases as the new shoots mature during the late spring and summer season, then it increases with age.

Summary

Four species of *Ephedra* occur at the Nevada Test Site and these separate into cold and hot desert species. *Ephedra* species grow slowly and in some years do not produce flowers or seeds. *E. nevadensis* has a clumping habit due to underground stolon production. Seedlings and cuttings of *E. viridis* and *E. nevadensis* were prepared and used for several studies. *E. viridis* grew somewhat better at a root temperature of 21°C than at either 28 or 16°C. Shoots of *E. nevadensis* do not accumulate sodium, are low in phosphorus and high in aluminum. Very young shoots are low in potassium and high in calcium in contrast to most plant species. *Ephedra* species are extremely sensitive to gamma radiation.

CHARACTERISTICS OF GRAYIA SPINOSA (SPINY HOP SAGE)

Grayia spinosa (Hook.) Moq. grows over much of the Nevada Test Site. The relative frequency of distribution for G. spinosa is about 3% (160 G. spinosa plants per hectare) in a section of the Rock Valley area where elevation is about 1100 m. Larrea divaricata is the predominant shrub in this area as it generally is elsewhere in the Mojave Desert. At elevations of about 2100 m in the Pahute Mesa area the relative frequency of G. spinosa is about 1%. The associated vegetation at this location is largely Artemisia species, typical of the Great Basis Desert. G. spinosa usually is an associated species but it can also be a codominant species or it can occur in nearly pure stands (Beatley, 1965). It is a dioecious shrub (Figures 1 and 2) that extends from the Great Basin Desert southward through most of the Mojave Desert (Benson and Darrow, 1954).

Description

Shreve and Wiggins (1964) give the following description of G. spinosa:

> Intricately branched shrub 3 - 12 dm high; branchlets usually spinose, sparsely stellate-scurfy in youth, bark glabrate and dark gray on older stems; leaves oblanceolate to oblong-oblanceolate, 0.5 - 4 cm long, rounded or obtuse at apex, gradually narrowed to a short, slender petiole, stellate-pubescent when young, soon glabrate; flowers crowded in terminal spikes or some in axillary clusters; fruiting bracts obovate to orbicular, 3 - 15 mm in diameter, lightly veined, lutescent or often tinged with red; seed 1.5 - 2 mm in diameter, dull. Arid plains and rocky hillsides, mostly Upper Sonoran Zone, eastern Washington to western margin of Colorado Desert, eastward to Wyoming, Colorado, and northern Arizona. March - June.

G. spinosa at the Nevada Test Site lives to be at least 20 years old, as indicated by the number of growth rings in the root crowns of median-sized shrub 4 to 6 dm in height and diameter. G. spinosa could not possibly put on more than 1 growth ring per year because of its strong summer dormant habit. It

Figure 1. Pistillate form of G. spinosa.

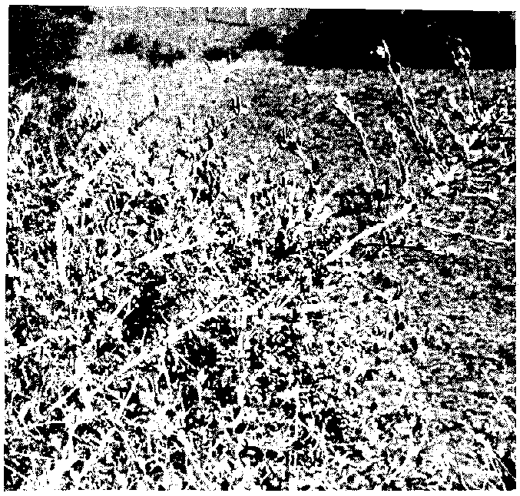
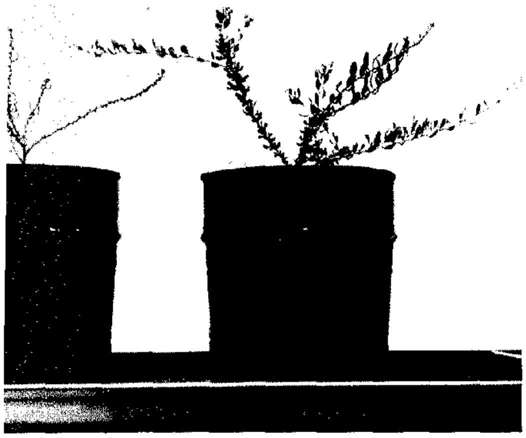


Figure 2. (left) Staminate form of G. spinosa.

Figure 3. (right) Rooted cuttings of G. spinosa.



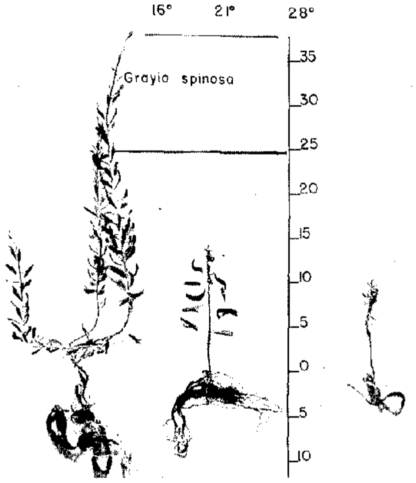
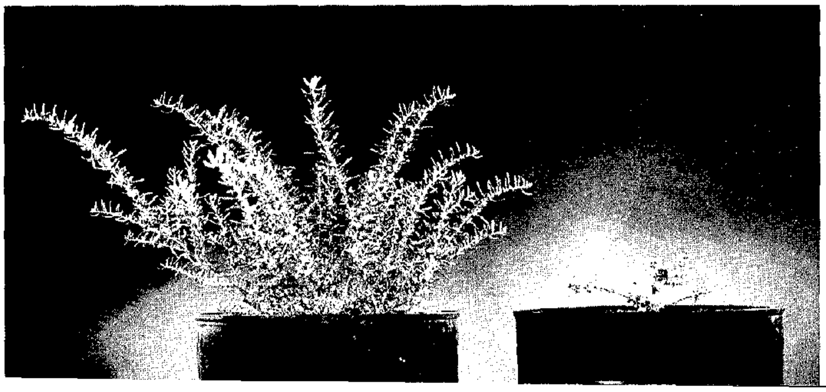


Figure 4. (left) Plant on right broke dormancy after chilling 2 weeks at 5°C.

Figure 5. (right) Growth of G. spinosa cuttings 60 days at varied root temperatures.

Figure 6. (bottom) Gibberellin added to plant at left broke dormancy of G. spinosa.



becomes completely leafless and dormant in relatively early summer and this dormancy is not broken either by late summer rains or by irrigation. August rains at the Nevada Test Site in 1967 resulted in resumption of growth of many shrub species, but not that of G. spinosa.

Reseeding is not common within our experience in the Larrea areas, except where supplementary irrigation was applied. In the summer of 1967, a large number of G. spinosa seedlings germinated and survived at a disturbed area study site on the Pahute Mesa. These seedlings grew to a height of 3 to 4 dm in the first year.

Rickard (1969) reported that G. spinosa and Sarcobatus vermiculatus can grow together, but that G. spinosa will accumulate potassium while S. vermiculatus accumulates sodium. Rickard and Keough (1968) reported that G. spinosa eliminated excess potassium by leaf abscission.

Experimental Results

Seed from G. spinosa germinated readily in vermiculite without special treatment. Cuttings from G. spinosa plants were brought from the Nevada Test Site and various experiments were made to test the ability of the material to root. Cuttings rooted most satisfactorily after dipping the tips into Hormodin No. 2 powder (0.3% IBA in talc) and placing them in vermiculite in a lathhouse. Rooting occurred within 6 weeks to 2 months (Figure 3). The lathhouse conditions provided relatively low humidity and cool day and night temperatures.

Rooted cuttings transferred to soil in pots grow very poorly under the normal glasshouse conditions (27° C or more daytime–18° C or more at night). Such cuttings often sit for months without growing. The plant on the right in Figure 4 was placed in a refrigerator at 5° C for 14 days and then returned to the glasshouse. The photograph was taken about 14 days after removal from the refrigerator. Since other plants had dormancy broken when grown in a lathhouse with night temperatures of about 13° C, the chilling requirement for G. spinosa may not be great but it is real. This requirement as yet has not been accurately determined. Soil temperature may be more critical to the growth of G. spinosa than a chilling requirement. Seedlings were exposed to different root temperatures for 60 days. G. spinosa seedlings grew much better at a low soil temperature (16° C) than at higher temperatures (21 and 28° C) (Figure 5).

The dormancy of G. spinosa also was broken by gibberellin (Figure 6). An application of 1.75 mg gibberellin to a single plant in one gallon of soil broke the dormancy. Increased growth, however, resulted from 7.0 and 35.0 mg applications. The treatments were effective for about 3 months although there was some carry-over effect into a second year. Gibberellins are involved in some kinds of dormancy (Vegis, 1964). The dormancy of G. spinosa is obviously regulated by the production of a growth substance in the roots which in turn is regulated by soil temperature.

G. spinosa is among the first of the shrub species to resume growth following winter dormancy. New flush growth generally is evident on G. spinosa in February at our lower elevation study sites. Its regulatory mechanisms permit it to complete a life cycle before soil moisture is exhausted. This shrub species gives marked growth response to supplementary irrigation following a winter season of relatively low rainfall (Figures 7 and 8). The size of leaf, number and size of new shoots, flowering and fruit set is very much dependent upon the amount of available soil moisture.

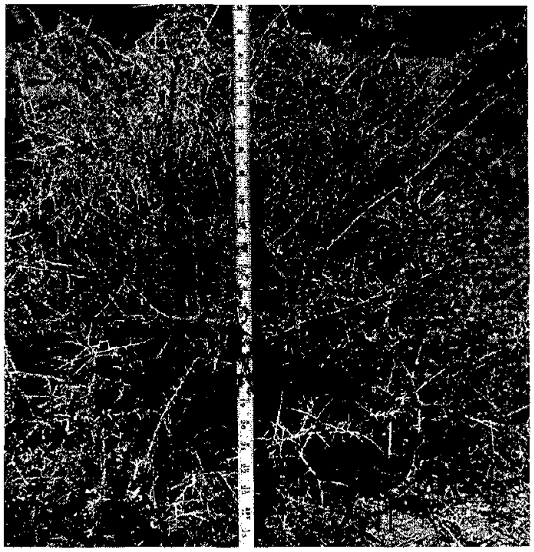
The mineral composition of G. spinosa from field study sites is given in

Table 1. Mineral composition of leaves of Grayia spinosa grown at the Nevada Test Site.

Location	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
			% of dry weight								ppm of dry weight							
Mercury Valley	.31	.22	7.34	1.83	1.18	.09	20	8	196	102	61	187	13	4.5	1.8	1.9	83	11
410 Road	.32	.10	9.90	2.12	.99	.17	2	3	246	160	96	435	31	7.5	1.3	2.0	68	10
Rock Valley A	.28	.13	7.18	2.55	1.07	.12	34	11	248	115	56	274	17	3.4	1.6	1.8	43	13
B	.12	.10	8.21	4.17	1.41	.08	33	18	190	184	50	204	3	3.1	2.1	3.3	53	12
Frenchman Flat	.15	.12	10.42	2.41	.82	.21	21	8	231	148	66	425	9	5.3	1.7	6.9	64	21
Pahute Mesa	.24	.14	9.98	1.93	1.12	.16	6	14	221	217	43	285	12	6.2	1.0	8.7	48	20
40-mi. Canyon	.31	.16	10.89	1.28	.60	.19	23	6	219	99	84	397	22	3.6	1.0	7.4	56	16
Yucca Mountain	.24	.05	13.67	.63	.97	08	23	13	153	263	43	124	5	4.1	1.2	6.4	41	6

Table 2. Mineral composition of leaves of Grayia spinosa grown in Yolo loam soil (pH 5.7 to 6.0) in the glasshouse at varied soil temperatures.

Soil temp. °C	Yield g/ plant	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
				% of dry weight									ppm of dry weight						
16	2.91	.87	.20	8.50	1.04	1.01	.30	111	10	509	78	76	633	197	3.8	2.6	8.6	34	83
21	1.07	1.98	.26	9.00	.63	.72	.10	90	32	202	73	43	171	31	3.5	1.3	2.0	28	42
28	26	2.72	.81	9.60	.42	.63	.04	101	18	143	29	36	43	2	1.2	.5	.7	21	39



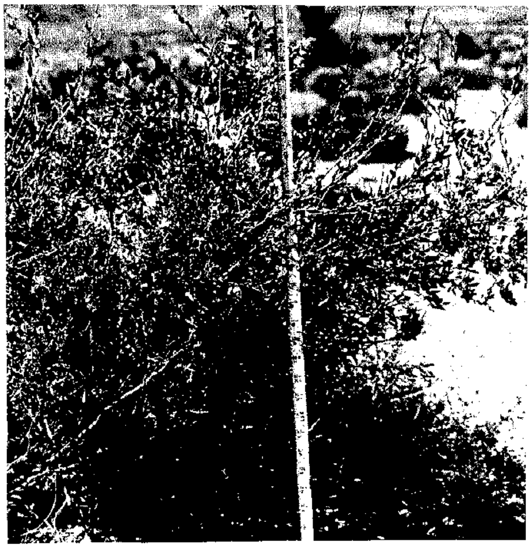


Figure 7. (left) Growth of *G. spinosa* shrub in area receiving 9 cm rainfall per year. Photos taken 10 June 1970.

Figure 8. (right) Growth of *G. spinosa* in area receiving an additional 15 cm of supplemental sprinkler irrigation.

Table 1. As mentioned above it tends to have high potassium contents and low sodium contents. Zinc and copper contents tend to be low. Mineral composition of young plants grown in Yolo loam at different soil temperatures (Figure 5) in the glasshouse is given in Table 2. Phosphorus, zinc, and copper contents were higher than for mature plants grown in the field. Phosphorus, sodium and potassium increased with temperature, while calcium, magnesium, iron, manganese, boron, aluminum, titanium, molybdenum, cobalt, nickel, strontium, and boron decreased with increasing temperature. This is different in many cases from other plant species, but the effect of soil temperatures on growth may explain much of the difference.

Atrazine applied at a level of 11 kg per hectare killed the *G. spinosa* on treated plots at the Nevada Test Site.

Gamma irradiation of 5 to 7 kR from a ^{60}Co source killed *G. spinosa* cuttings. This species is relatively resistant to radiation compared to some other cold desert shrub species (i.e. *Artemisia*, *Ephedra*, *Juniperus*, species) but it is quite sensitive when compared to some of the warm desert species (*Atriplex*, *Larrea*, *Yucca* species).

Summary

Grayia spinosa is a widely distributed dioecious shrub, but adapted to relatively low soil temperature conditions. It has a pronounced dormancy which can be broken by chilling or by soil application of gibberellin. Soil temperature of about 18° C is required for its optimum growth. Higher soil temperature hastens dormancy. Its field growth occurs in early spring and dormancy occurs rather early. Dormancy appeared to be regulated by a root-produced growth substance. Seeds germinate readily. Seedlings can become established and new shoots can attain the height of old shrubs in one season with adequate moisture. Rooted cuttings can be made from *G. spinosa* if treated with IBA in talc and kept in a lathhouse for rooting. Leaves of the species are very high in potassium and low in sodium. Mineral composition is greatly related to soil temperature. This species gives marked growth response to supplementary irrigation but only if soil temperature is favorable.

CHARACTERISTICS OF LARREA DIVARICATA (CREOSOTE BUSH)

Larrea divaricata Cav. (creosote bush) is a dominant shrub species in the deserts of the southwestern United States, occupying somewhere between 20 and 35 million acres (Shreve, 1951). It is also prominent in deserts of Central and South America. This shrub has been spreading rapidly in recent decades (Buffington and Herbel, 1965; Yang, 1961). It is the subject of several recent studies (Barbour, 1968, 1969; Chew and Chew, 1965; Woodell et al., 1969). Some observations concerning its characteristics in the transition zone between the Great Basin and Mojave Deserts are described here. Field study areas are located at the Nevada Test Site in southern Nye County, Nevada. Laboratory studies also have been made on this shrub in glasshouse and controlled environment facilities.

Description

The nomenclature for L. divaricata is based on the assumption that the species at the Nevada Test Site is similar to that of L.divaricata in South America. Although controversy in nomenclature still exists, L. tridentata of the southwest deserts is thought by some experts to be the same species. Shreve and Wiggins (1964) describe Larrea Cav.:

> Strong-scented evergreen shrubs with several to many brittle, strongly nodose, slender branches from a branching root crown. Leaves opposite, of 2 leaflets connate at base, sessile or short-petiolate. Stipules small, persistent. Flowers solitary, axillary. Sepals 5, imbricate, woolly outside, caducous. Petals 5, yellow, obovate to spatulate, hypogynous. Stamens 10, each adnate basally to outside of a membranous, 2-toothed or 2-cleft, sometimes laciniate scale nearly as long as filament. Ovary short-stipitate, 5-celled, globose to ovoid, pilose, each cell 5-6-ovuled. Stigmas 5. Fruit globose to ovoid, 5-angled, separating into 5, indehiscent, 1-seeded carpels.

L. divaricata has been the subject of some early studies. In 1904 and in 1909 Spalding reported some of its essential characteristics. He suggested that it does not grow where water persists for a long period of time, that it is both deep and wide rooted, that it is extremely drought resistant and that a varnish on the leaves contributes to its drought resistance. Duisberg (1952) described this leaf resin in more detail. Spalding (1904) reported that the leaves themselves will take up water from the atmosphere and that the plants decrease their leaf surface by some leaf abscission during a period of extreme drought. Runyon (1934) reported that L. divaricata leaves survive even if dried below 50% moisture. He also reported that naked buds and partially expanded leaves are drought resistant.

Shreve and Wiggins (1964) reported that L. divaricata grows on deep alluvial soils, on the edges of alkaline flats, on rocky slopes of volcanic hills, but rarely on granitic slopes or soils. Livingston (1910) suggested that oxygen deficiency may keep this shrub from developing in dense, moist soils. It grows on caliche soils (Dalton, 1962; Shreve and Mallery, 1933). Shreve and Wiggins (1964) also reported that it is extremely drought resistant, more so than most other plants, but that it readily responds to water and is adapted to a wide range of climatic conditions. Spalding (1904) found that its transpiration rate was increased 8-9 times when irrigated and suggested that it was not a true xerophyte—rather a mesophyte. Ashby (1932) suggested the same thing.

Leaves abscise during drought, but some always remain. Ferguson (1950) reported that severe drought can kill L. divaricata. Strain and Chase (1966) suggested that, in addition to dropping some leaves during drought and maintaining fewer leaves, the adaptation of L. divaricata to hot temperatures may be related to its ability to successfully carry on photosynthesis after high temperature acclimation.

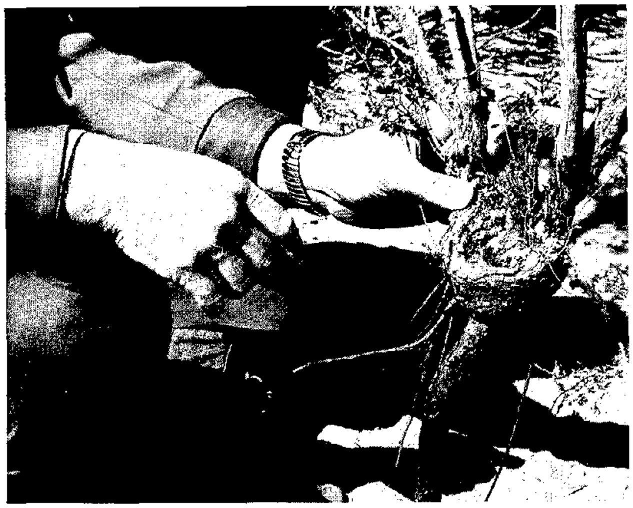
Observations

Shreve and Hinckley (1937) suggest that L. divaricata attains an age well in excess of 100 years as observed here (Figure 1). Mature plants have a number of slender branches growing from the crown of the root (Figure 2). In time the root crown may break apart to form individual plants utilizing segments of the original root system. These segmental plants may in turn live as long as the original parent did before segmenting occurred (Figure 3). Age can be roughly estimated from growth rings in root crowns (Figure 5) which may become 20-30 cm thick. Flowers are borne near the ends of the youngest shoots and appear following winter rains. Although not in great number, flowers appeared following an August rain in 1967 at the Nevada Test Site and many of them set and matured seed. Fruits reach maturity in six to eight weeks, and the hairy covered seeds are widely disseminated.

L. divaricata seeds germinate readily in vermiculite in the glasshouse without special precaution. There are temperature and water limits, however (Went and Westergaard, 1949). Seed germinate sufficiently often in the desert to maintain the species, but survival of the new seedling is a rare event ex-

Figure 1. Old L. divaricata shrub in the Rock Valley area of the Nevada Test Site. Note large crown with large amounts of dead wood. This individual shrub is probably well over 100 years old according to growth rings.

Figure 2. L. divaricata plant showing nature of branch growth from crown of root. Note that very young as well as intermediate aged shoots are present with the older shoots.



cept when the proper sequence of rainfall occurs. Shreve and Wiggins (1964) reported that seed germinate in July or August if moisture is available, but that the number of seedlings is few among old stands. Shellhorn (1955) germinated L. divaricata at 37°C. Dalton (1962) reported 35°C as the optimum temperature for germination. Went and Westergaard (1949) reported that seed germinated at 15-16°C following rain, but not at 8-10°C. On cleared or cultivated land they found that the number of seedlings was high and that they grew densely until 60-80 cm tall when some individuals repressed others until the final mature stand was approximately like that which naturally occurred.

L. divaricata are fragrant plants and the leaves excrete a terpene which may be in part responsible for desert haze when oxidized by sunlight (Rasmussen and Went, 1965).

The northern limit for L. divaricata is in southern Nevada and southwestern Utah (Shreve and Wiggins, 1964). In this area it follows a contour of about 1200 meters. It is limited by frost. Shreve (1940) reported that 6 consecutive freezing days can kill it, but this is not always the case. It grows at 2600 meters near Mexico City and below sea level in Death Valley. In southern Nevada, L. divaricata communities are well developed on lower bajadas up to about 1400 meters elevation and they extend up to about 1700 meters on arid, south-facing slopes. Isolated stands may be found as high as 2000 meters (Bradley and Deacon, 1965).

L. divaricata dominates much of the south part of the Nevada Test Site, but conditions for its growth are marginal there. Rainfall is low (10-12 cm annual mean) and extremely irregular. The ecosystems containing L. divaricata appear to be old and stable. The number of L. divaricata per hectare in Arizona varied from about 500 to 1000, and Chew and Chew (1965) suggested 1000 for the stable state. The Rock Valley area of the Nevada Test Site has about the same number. Except for a wash in which an artificial stream flowed for several years and along roadways, there is little evidence of new permanent reseeding (Figure 4). Seedlings have been observed to germinate under natural conditions with sufficient rainfall but evidently very few survive.

The life of a L. divaricata shrub is suspected of being around 100 years (Chew and Chew, 1965; Shreve, 1951). The L. divaricata root crowns in cross section (Figure 5) illustrate the growth ring structure of an individual plant of about 80 rings before segmenting and a plant that had begun to segment. The 1965-1966 rains (up to 25 cm) in some sections of the Nevada Test Site apparently resulted in no new surviving seedlings in the Rock Valley area, but there were some in the Frenchman Flat area. Overhead sprinkler irrigation at a

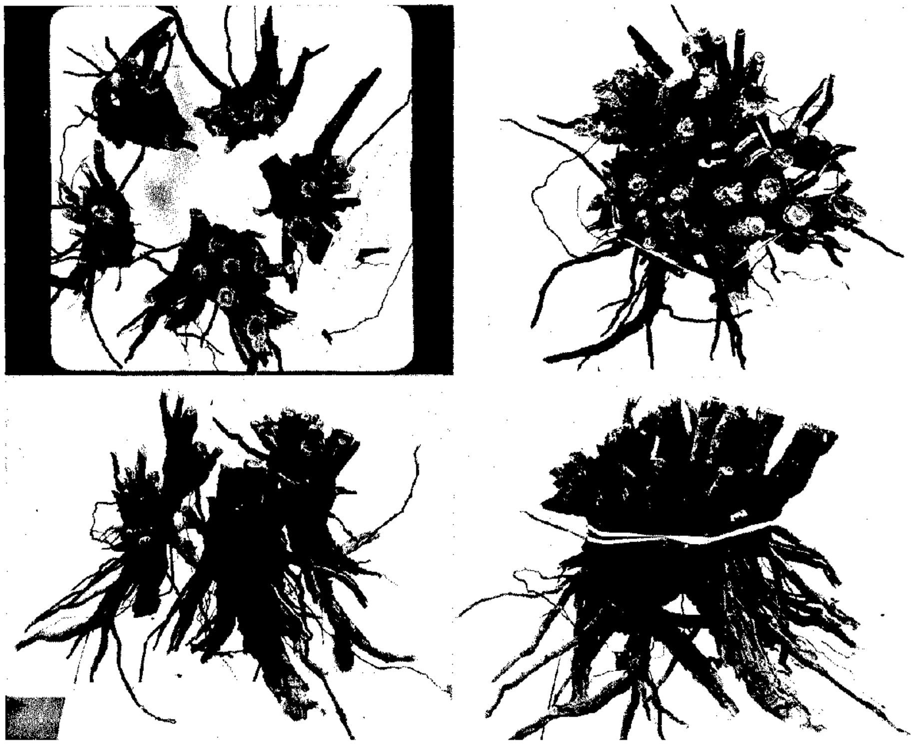


Figure 3. Root crown of L. divaricata that had segmented into individual plants utilizing segments of the original root system. When removed from the field these segments were separated by 5 to 10 cm of soil that had worked between them. This composite photo shows how nearly these segments still fit together even after the lapse of many decades.

study site near Mercury, Nevada, resulted in the establishment of new seedlings in 1968-69 and 1969-70 with monthly additions of moisture (3-5 cm) from April through September. Seedling survival is probably a precarious matter as suggested by Barbour (1969). A succession of favorable climatic events seems necessary and these are in low probability. New seedlings can become deep rooted rapidly. Seedlings in the glasshouse have grown to depths of 100 cm at a rate of 2-3 cm a day with seedlings only 2-3 cm tall (Figure 6); obviously this is a remarkable survival characteristic. Even so, the majority of new seedlings in the desert evidently do not survive.

Age classes are more evident in some stands than others in Nevada. Plants in a plot 25 m in diameter near Lathrop Wells, for example, varied in the dimension, height and width by a factor of over ten. The number of plants on this basis for various classes of volume were 6 less than 0.10 m^3, 16 between 0.10 and 0.30 m^3, 18 between 0.30 and 0.50 m^3, and 5 over 0.50 m^3. This indicates a fairly continuous age structure.

Excess water as well as drought can kill new seedlings. Continuous water

Figure 4. L. divaricata reseeds along highways and the old ones grow better because of fewer limiting factors.

in a stream bed for 90 days killed the shoots of new seedlings that had grown there because of some intermittent water flow about two years earlier. The roots of many plants that supposedly were dead, however, sprouted new shoots. Response to standing water may be one reason why L. divaricata does not grow near the playas in southern Nevada. Playas of closed drainage basins have a typical L. divaricata ecotonal line above the playa (see page 258). The occurrence of fine or dispersed clay particles in the root zone, lack of soil aeration, and the presence of salinity all may contribute to the failure of L. divaricata to grow near the playas, although the species is reported to have a wide range of tolerance. L. divaricata has been observed to grow adventitious shoots from cut root pieces in the field (Figure 8). Vegetative growth from roots may be a major means of reproduction. It also grows from injured crowns and has apical dominance.

The growth of L. divaricata is generally quite scrubby in the Nevada Test Site area compared to its growth in many areas of the southwest deserts. Along highways the shrubs are usually much larger than those a few meters off the highways (Figure 4). Less competition for water and possibly for nutrients can be suspected as causes for the improved growth. The flow of water in a wash for several years greatly improved L. divaricata growth. The water contained a small amount of nitrogen (about 5 mg/liter) and L. divaricata foliage in the wash contained over 20% more nitrogen than the poorly growing

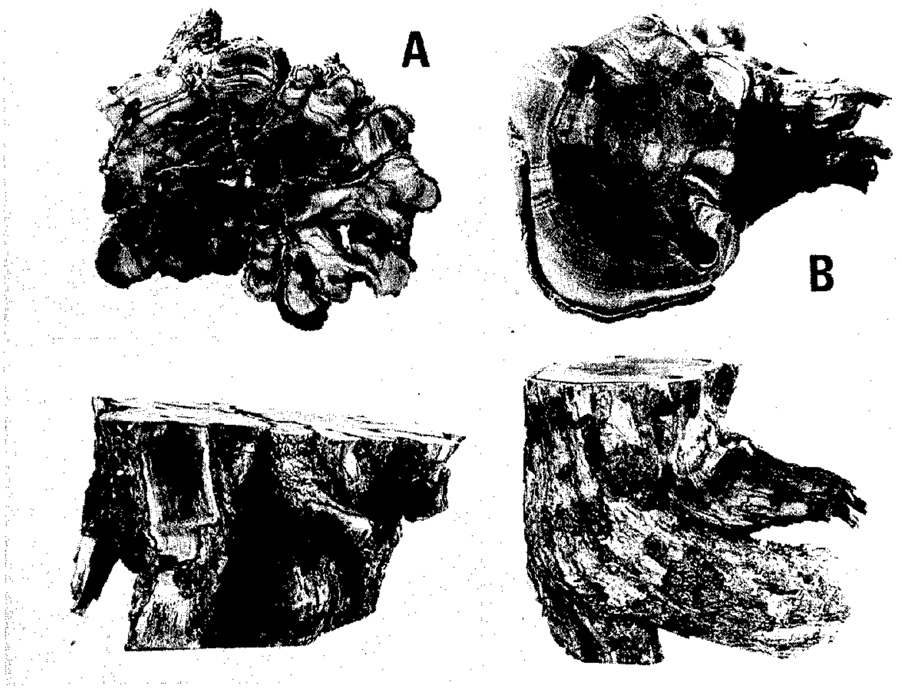


Figure 5. Growth rings in a L. divaricata plant from the Rock Valley area of the Nevada Test Site. Crown A has more than 100 rings plus several supplementary ring structures of crown-sprouted shoots. Crown B has over 80 growth rings.

shrubs above the wash (2.1 vs 1.6% N of dry wt). Almost exactly the same condition in nitrogen content was observed for shrubs growing near a highway and for those growing off the highway (2.0 vs 1.6%N).

The biomass production of L. divaricata in Arizona was reported to be about 1000 kg dry weight per hectare per year. The L. divaricata population had a standing biomass of about 3400 kg per hectare (Chew and Chew, 1965). At our study sites where L. divaricata is a codominant species, the annual productivity and standing biomass varies from 1/10 to 1/4 of that observed in southern Arizona. Dominant stands of L. divaricata fare much better, but the productivity and biomass levels reported by Chew and Chew are found only in localized areas where ideal edaphic conditions prevail. In areas where L. divaricata is present at the Nevada Test Site it provides up to 50% of the canopy coverage of the approximately 12% of cover (Beatley, 1965).

L. divaricata nearly always grows in association with other shrubs at the Nevada Test Site. Beatley (1965, 1969) has described six major associations with L. divaricata. An example of its codominance at the Rock Valley study site is shown in Table 1; Larrea-Franseria dumosa is the most common association (Beatley, 1965, 1969). L. divaricata reaches its highest elevation at the Nevada Test Site at about 1500 meters (Beatley, 1965, 1969). This is

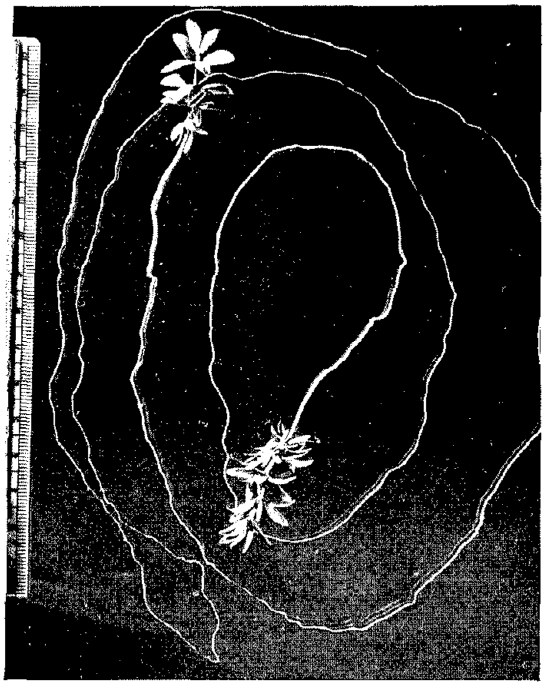


Figure 6. Root growth of two two-month-old L. divaricata seedlings. The roots elongated from 2 to 3 cm per day.

lower than in the Sonoron Desert (Shreve and Wiggins, 1964). It becomes associated with Coleogyne at about 1300 meters (Beatley, 1965, 1969).

Table 1. Relative abundance of shrub species in Rock Valley, Nevada Test Site (a transitional area between Mojave and Great Basin Deserts).

Species	Relative frequency in two study plots at Rock Valley*	
	A	B
	%	
Larrea divaricata	20.6	22.0
Lycium andersonii	18.5	25.2
Lycium pallidum	10.9	0.0
Franseria dumosa	18.5	16.8
Grayia spinosa	4.4	2.1
Coleogyne ramosissima	4.4	1.5
Eurotia lanata	3.3	1.5
Krameria parvifolia	4.4	22.0
Ephedra nevadensis	14.1	9.5

*Average number of plants per hectare of all species was 5586 and 4272 for plots A and B respectively.

Data collected by William Martin. (See page 396.)

L. divaricata has an evergreen habit. New leaves are produced in the spring and in the summer following rains. They develop in old leaf nodes. They abscise more or less continuously, but especially during drought. The guard cells are reported as not capable of opening (Warskow, 1965).

The root systems are not always deep but they can occupy the soil that is available depending upon the density of shrubs (Figure 8).

L. divaricata provides food for animals. It is host for a number of insects. Jackrabbits at the Nevada Test Site clip off one-year-old stems during the winter months when there is little or no herbaceous vegetation. Jaeger (1948) reported that rabbits clip off L. divaricata stems to sharpen their incisor teeth. They rather seem to eat these tender stems but discard all the leaves and that part of the stem which is still green colored (Figure 9). Leaves and the green colored stem are bitter. Jackrabbits are known to feed on shrubs (Chew and Chew, 1965).

Figure 7. Adventitious shoot growth from root of L. divaricata which was severed by a trench cut. Note that the new growth is on the root piece not connected with the main plant. Such shoots readily develop on this species.

Figure 8. Part of the root system of 3 different L. divaricata shrubs excavated in the west Jackass Flats area. Note the lateral habit, the depth of which corresponds closely with the depth of penetrating moisture. This lateral branching makes possible the use of water supplies in the soil, even where soil is not covered with shrubs.

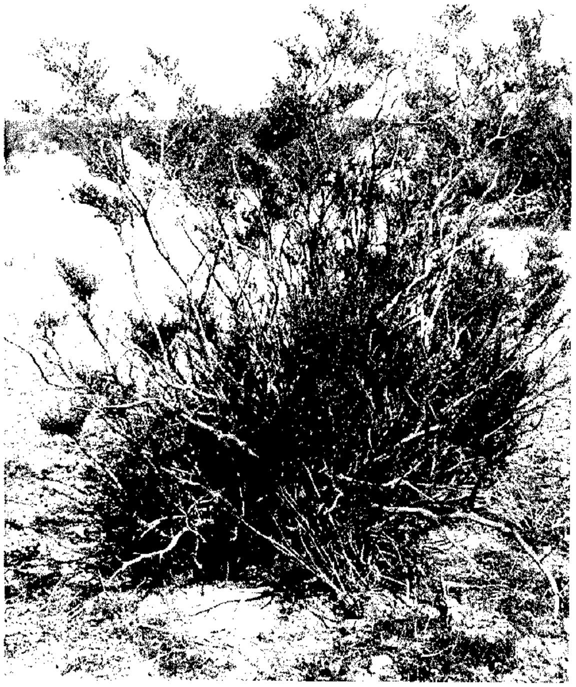


Figure 9. L. divaricata shoots have been clipped off by jackrabbits and the green leaves left on the ground beside the plants.

Experimental Results

The mineral composition of *L. divaricata* from the Nevada Test Site was determined from samples collected in the field in 1969 (Table 2). Several important conclusions emerge from the data. The leaves are low in sodium, zinc, copper and relatively low in phosphorus. They are moderately high in calcium and silicon. The magnesium, potassium, and boron contents are equal to those of other plants. The resistance of *L. divaricata* to sodium accumulation is illustrated in Table 3.

Table 2. Mineral composition of *L. divaricata* leaves of plants grown at the Nevada Test Site.

Location	P	Na	K	Ca	Mg	Si
		% of dry weight				
Frenchman Flat	.31	.10	3.43	1.55	.46	.50
Area 410	.25	.04	2.44	1.36	.19	.24
Mercury Valley	.14	.05	1.96	1.69	.27	.23
Rock Valley	.21	.05	2.37	1.46	.23	.23
Frenchman Flat B	.18	.06	2.18	1.80	.32	.31
Near Sedan Crater	.28	.05	1.90	1.81	.19	.29

	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
			ppm of dry weight									
Frenchman Flat	>10	1.3	497	73	85	875	135	1.5	.6	1.8	80	46
Area 410	>10	1.5	252	28	107	431	46	1.3	.5	1.2	69	14
Mercury Valley	>10	1.9	244	39	114	445	40	1.1	.5	1.0	105	23
Rock Valley	>10	3.0	291	37	68	429	19	0.5	.5	.8	84	22
Frenchman Flat B	>10	1.0	327	54	190	639	84	1.8	.5	1.2	86	14
Near Sedan Crater	>10	2.0	322	40	142	569	58	2.1	.5	1.5	66	13

Table 3. Effect of varying levels of Na_2SO_4 on sodium content of *L. divaricata* plants in solution culture.

Plant Part	Treatment me/l Na_2SO_4		
	0	30	90
		% of dry weight	
Leaves	0.08	0.30	0.57
Stems	0.09	0.33	0.29
Roots	0.10	0.39	0.50

Means of determinations for 3 plants.

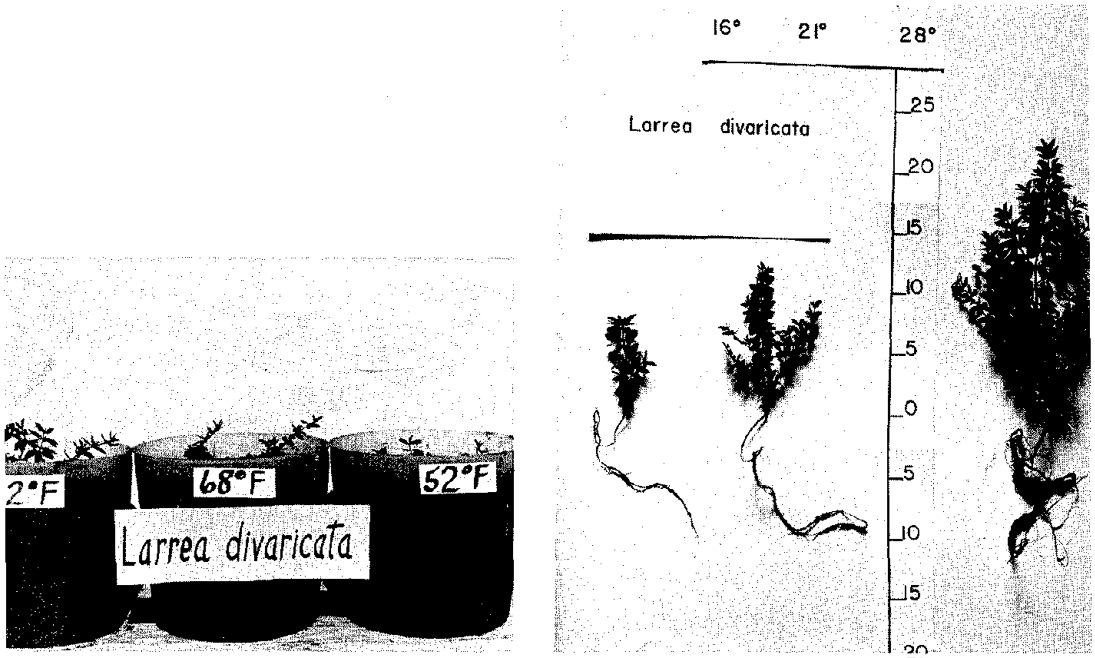


Figure 10 a and b. L. divaricata seedlings grown in two different experiments in temperature tanks for 60 days to control root temperature.

Distribution of L. divaricata at different elevations may be at least in part explained by its response to soil temperature. At higher elevations it grows in protected places and on south-facing slopes. L. divaricata seedlings do not flourish with a cool soil temperature (Figures 10 a and b). In fact water sensitivity of L. divaricata seems to increase with a decrease of soil temperature. The soil in the test was Yolo loam; the growth period was 60 and 90 days. Yield and mineral content of some of these plants are in Table 4. Zinc and copper contents when grown in this soil were much higher than in those grown in the field. Copper and molybdenum increased with temperature, but some elements decreased with temperature because of increased growth of plants (potassium and calcium).

Table 4. Yields and mineral composition of L. divaricata shoots grown in Yolo loam at different soil temperatures.

°C	Dry wt per plant (mg)	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Mo	Sr	Ba
			% of dry weight						ppm of dry weight					
						First experiment								
10	30	.72	-	-	-	-	-	-	-	-	-	-	-	-
21	285	.72	.17	2.90	2.01	.36	70	46	296	296	205	7.8	56	83
37	675	.71	.16	2.58	.81	.24	125	50	507	180	95	5.5	31	68
						Second experiment								
16	200	.54	.11	4.71	2.58	.45	39	11	201	64	78	3.8	85	123
21	380	.56	.10	3.68	2.70	.36	28	13	297	67	75	3.2	83	93
28	2400	.48	.06	3.07	2.06	.39	39	17	207	50	136	6.0	62	85

Figure 11. Growth of L. divaricata seedlings in soils of varying pH, $CaCO_3$, and salt contents. Aiken is acid, Hacienda is calcareous, and Nye Canyon is saline.

L. divaricata seems to have a wide tolerance for soil pH differences. It is native to calcareous deserts, however (Waterfall, 1946). Seedlings grew almost as well in Aiken soil of pH 6 as in highly calcareous soils (Figure 11). Dry matter production was slightly decreased by acidification with 2% sulfur of Yolo loam (Table 5). Addition of $CaCO_3$ slightly increased dry matter production. Micronutrient contents were related to soil pH. Zinc contents and, to a lesser extent, copper of plants grown in the $CaCO_3$ treated soil were very low like at the Nevada Test Site (Table 2), but they increased greatly with decrease in soil pH. Iron as well as molybdenum contents decreased with pH. The manganese content increased greatly at the low pH.

Table 5. Shoot yields and mineral composition on the dry weight basis of leaves of L. divaricata grown in Yolo loam soil with and without excess $CaCO_3$ and sulfur.

Measurement	$CaCO_3$ (pH 7.5)	Control (pH 6.0)	Sulfur (pH 4.2)
Leaf wt, g/plant	6.23	5.43	4.52
Stem wt, g/plant	2.01	2.19	2.13
Ca, %	1.16	0.89	0.83
K, %	2.90	2.28	2.49
Mg, %	0.27	0.24	0.31
Na, %	0.14	0.11	0.09
P, %	0.46	0.33	0.38
B, ppm	70	56	80
Cu, ppm	18	31	66
Fe, ppm	205	204	144
Mn, ppm	66	28	240
Co, ppm	+	1.1	1.0
Mo, ppm	10.2	1.4	1.2
Zn, ppm	4	32	63

Means of determinations from 3 plants.

L. divaricata leaves may absorb water vapor (Spalding, 1904). Tests here indicate that leaves maintained at 100% humidity did absorb some water vapor. The seasonal water content of L. divaricata leaves varies greatly (Table 6). Leaf water content was decreased in cold weather and with dry soil; irrigation increased it. The relative photosynthetic rate at different leaf moisture levels is as yet unknown, but leaves remain living at very low water levels.

Table 6. Seasonal water contents of L. divaricata shoot tips from the Nevada Test Site.

Month	Non-irrigated plot	Irrigated plot
	% water	
December	31.5-37.1	46.7
July	43	54
September	31-37	47-54

Table 7. Response of L. divaricata to varying degrees of pruning (pruned March 15, 1967—measured January 6, 1968).

Degree of pruning	Length of new shoot growth
	cm
None	2-5
Moderate	8-10
Severe	20-30

L. divaricata in the stream bed was in new flush in February-March 1968 and was injured by a freeze of about -10° C. New growth was similarly frozen in 1969.

Figure 12. (left) L. divaricata shrub completely defoliated by pruning on March 14, 1967.

Figure 13. (right) Same shrub shown in Figure 12 in August 1967 after shrub had started to respond to summer rains.

Pruning greatly stimulated the growth of L. divaricata (Table 7). On March 15, 1967, several L. divaricata shrubs were subjected to various degrees of pruning (Figures 12, 13). The new growth was inversely proportional to the severity of pruning. On the other hand, the amount of flowering was inversely related to the new growth. Severely pruned plants did not flower in 1967; moderately pruned ones had only about half as many flowers per unit shoot as did nonpruned plants. All flowered in 1968 and thereafter.

The thinning out of L. divaricata seedlings has been studied in a 90 x 45 x 45 cm container of soil in which 30 seedlings were transplanted in 1967. Twelve months later only 15 plants remained and of these only 5 were large. The other 10 were being shaded out by the larger ones. Chemical toxicity did not seem to be involved.

Chase and Strain (1966) were unable to get rooted cuttings of L. divaricata. In studies here, stem cuttings taken from mature shoots did not root, but those taken from some 1- to 1.5-year-old seedlings did root (Figure 14). The technique involved use of Hormodin 3 (0.8% IBA in talc). Tips 15-30 cm long were dipped in Hormodin 3 and placed in flats of vermiculite or soil in a mist house. Rooting occurred in about 1 month, but was variable; and cuttings from some seedlings rooted much better than those from others. Cuttings rooted better in soil than in vermiculite.

L. divaricata is fairly resistant to gamma radiation. In the spring of 1967, L. divaricata seedlings were irradiated with 0, 25, 50, 75, 100, 150, 200, and 300 kR in a single exposure with a ^{60}Co source for each plant. The roots were protected with lead bricks (5 cm). In about 2 months the plants exposed to the 300 kR level started to die and this progressed down to the 25 kR level within 3 months after irradiation. Shoots of seedlings exposed to 25 kR were dead, but new shoot growth emerged from the root bases (Figure 15). L. divaricata is definitely more resistant to ionizing radiation than are some other plant species. Its nuclear and interphase chromosome volumes (Sparrow et al., 1968) are intermediate to those of other plant species, and its resistance does seem to be related to these factors. Some radioecological implications of L. divaricata have been reported by Rickard (1963).

Figure 14. Rooted L. divaricata cuttings.

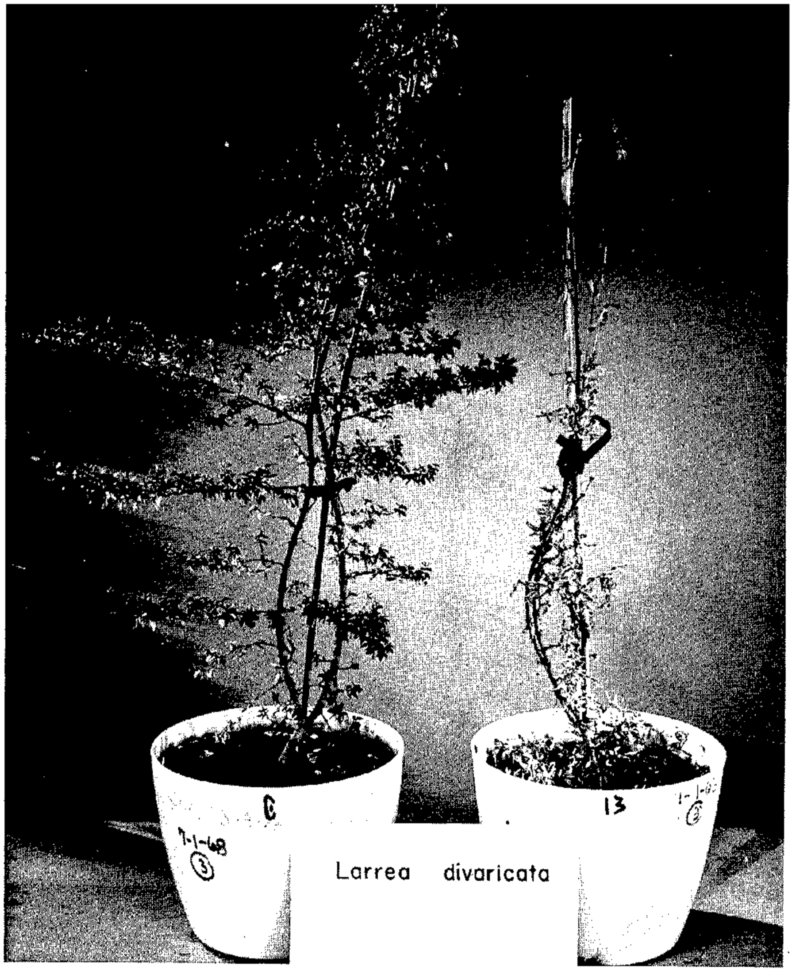


Figure 15. Response of *L. divaricata* to ionizing irradiation. New shoot growth is emerging from the crown of the shielded root. Root of plant on right was exposed to 25 kR.

Seedlings and rooted cuttings of *L. divaricata* did not flower in the glasshouse until they were about 2-years old; mature seed was produced the third year. Individuals irradiated with 28, 32, and 36 kR of gamma radiation 10 months previously tended to flower more than those not irradiated. A night temperature of about 26° C was necessary for flowering of *L. divaricata* under some conditions. Flowering in the glasshouse occurred earlier in the spring for a wide-leaf clone than for a narrow-leaf clone. The data of Chew and Chew (1965) indicate that, even in seasons of favorable rainfall in southern Arizona, no seeds are borne by plants younger than 13 years.

As elsewhere in North America (Yang, 1967a, 1967b, 1968), *L. divaricata* is present in the Nevada Test Site as two major ecotypes (Figure 16) with considerable variation due to cross breeding. Yang(1967a, 1967b) reported that the slender leaf form has more tolerance for low temperature and less tolerance for low moisture than the wider-leaf form (Yang, 1967a, 1967b). He suggested that the slender-leaf form occurs in the Sonoran Desert, that the broad-leaf form occurs in the Chihuahuan Desert, and that both occur in the Mojave Desert. The two have different chromosome counts, 26 and 52 for narrow and wide,respectively (Yang, 1967a, 1967b, 1968). A South American rel-

Figure 16. Two ecotypes of L. divaricata.

Figure 17. L. nitens, a South American relative.

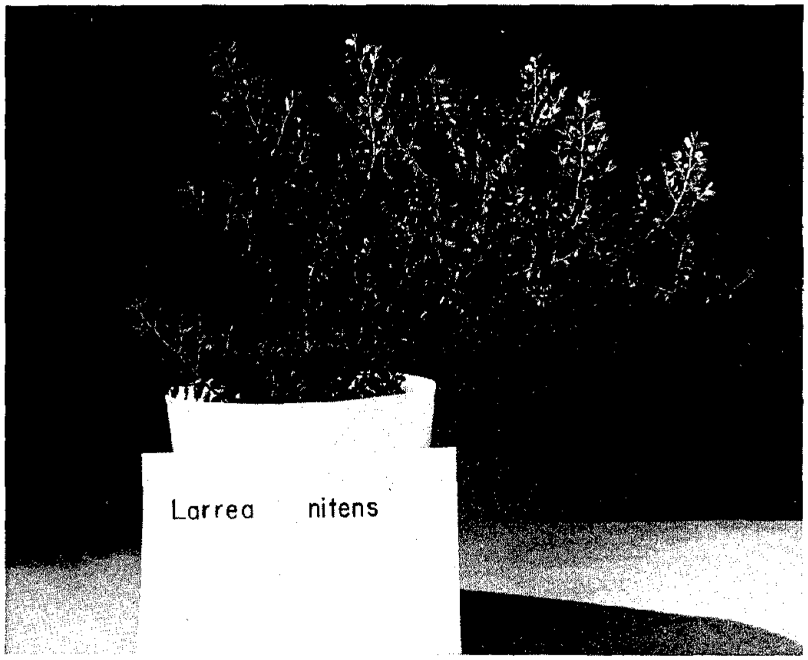


Table 8. Seasonal mineral contents , 1969 – *Larrea divaricata* (dry weight basis).

Sampling date	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Co	Ni	Mo	Sr	Ba
			%										ppm					
Leaf tissue																		
11 Feb	.20	.018	0.93	1.64	.25	.18	31	17	365	52	74	399	17	0.8	3.6	2.0	53	9
17 Mar	.13	.037	1.00	1.67	.32	.28	22	8	532	57	95	707	21	T	3.0	3.1	57	12
4 Apr	.18	.061	1.22	1.49	.33	.42	25	7	749	58	98	836	33	T	3.1	3.0	49	12
21 May	.17	.049	2.17	1.62	.29	.18	23	7	220	37	92	268	10	T	1.0	2.8	47	8
19 June	.21	.066	1.88	1.72	.26	.12	27	8	224	47	170	319	22	T	2.2	3.8	58	8
29 July	.21	.041	1.72	1.47	.31	.15	21	8	264	62	129	378	15	T	3.3	2.2	54	9
24 Sept	.24	.071	1.09	1.90	.39	.22	19	4	778	84	156	457	28	T	1.7	2.7	68	14
31 Dec	.21	.037	1.33	1.93	.32	.18	36	29	232	75	125	389	12	1.1	5.1	1.4	72	15
Stem tissue																		
11 Feb	.14	.042	0.96	1.04	.17	.30	15	15	537	28	39	614	26	0.9	5.7	1.8	52	13
17 Mar	.09	.064	1.10	0.77	.23	.53	22	8	943	34	52	951	29	T	3.6	2.9	44	16
4 Apr	.11	.093	1.18	0.91	.20	.44	17	8	753	29	46	822	29	T	3.6	2.3	47	15
21 May	.12	.055	1.99	0.79	.22	.16	14	9	354	22	36	368	11	T	4.2	2.5	48	12
19 June	.16	.058	1.72	1.04	.18	.15	21	8	368	24	47	376	24	T	3.3	T	62	12
29 July	.15	.034	1.59	0.88	.22	.21	24	10	404	27	36	332	12	T	5.4	1.0	61	12
24 Sept	.11	.053	1.23	1.05	.28	.35	16	16	785	42	69	449	29	T	3.3	1.8	62	16
31 Dec	.16	.027	1.42	0.98	.21	.28	24	19	256	37	47	341	8	T	3.0	T	47	18

ative, Larrea nitens (Figure 17), germinated readily and was successfully grown in the glasshouse. Grafting compatibility has been demonstrated between this species and L. divaricata from the Nevada Test Site.

Data for mineral composition of L. divaricata leaves and stems on a seasonal basis are in Table 8. Because leaves are on this species continually, and since there often is new growth response to summer rains the materials sampled may not always reflect increasing age of leaves. This may be the reason for the decrease and increase with season in phosphorus content in contrast for example to Franseria dumosa (see page 160). In fact leaf and stem tissue of L. divaricata were quite resistant to change in composition with season for most of the mineral elements. Boron in leaves, to a certain extent, was an exception in that it showed the aging process with progressive increases in content.

Summary

Larrea divaricata is the most common shrub on a large portion of the Nevada Test Site. It is extremely drought resistant and well adapted for survival in the desert, reaching ages probably of well over 100 years. Shoots continually die and new ones arise from the crown. Leaves are functional at relatively low water contents. Germination of seed occurs under relatively warm and moist conditions, but survival is rare. Rapid depth of rooting is one of its survival mechanisms. It branches laterally and occupies much of the soil not covered by other shrubs. It responds to summer rains and may set seed a second time in one year. Limiting factors for its growth under natural conditions include water and mineral nitrogen. Good soil aeration is necessary and it does not spread into areas where water stands for periods of time. It is widely spaced but is in clumps with other species and does not seem to compete with itself by chemical means. Spacing can be random, clumped, or regular. Being a hot desert species, it prefers warm to hot soil; but is not completely dormant during the winter season when air temperatures drop below freezing. It can be injured by frost but can recover. It is adapted to a wide range of soil pH even though it is native to calcareous areas high in pH and seems to prefer calcareous soil. Its mineral analysis revealed that it is low in zinc and copper when grown in calcareous soil. It tends to exclude sodium and tolerates little of it. It responds vigorously to severe pruning, but in the first season flowering was decreased by pruning. Ecotypes contribute to its variability. Rooted cuttings were made from one-year-old seedlings, but not from much older plants. Adventitious shoots grow from old severed roots. One-year-old L. divaricata wood is used for food by jackrabbits. L. divaricata is more resistant to ionizing radiation than are many other species.

Postscript: In his "Supplement of a California Flora," 1968, Munz gives the following nomenclature for the shrub referred to as L. divaricata:

> L. tridentata Sesse & Mocino for N. Am. plants according to Porter (Contr. Gray Herb. 192: 110-113. 1963). Lft.-veins usually dark, not lined with hairs (lined with white hairs 1 - 2 mm long in S. Am.); lfts. obliquely lanceolate to falcate (not obovate to elliptic); stipules obovate, acute to short-acuminate, 1 - 4 mm long, free from stem (not broadly ovate, rounded to obtuse at apex, 1 - 2 mm long, clasping the stem).

CHARACTERISTICS OF *LYCIUM* SPECIES

Three species of *Lycium* grow at the Nevada Test Site. Two of these, *Lycium pallidum* Miers (Figure 1) and *Lycium shockleyi* Gray (Figure 2) are confined mostly to specific locations; *L. pallidum* is found in Rock Valley and parts of Jackass Flats and Frenchman Flat, while *L. shockleyi* is found only in the southeast portion of Frenchman Flat (Beatley, 1965, 1969). *Lycium andersonii* Gray (Figure 3) is more widely distributed. Figure 4 compares leaf forms of the 3 species. *Lycium* occurs in association with other species. According to Beatley (1965, 1967, 1969) the most common association, perhaps, is *Larrea-Grayia-L. andersonii* occurring in areas in Mercury Valley, Jackass Flats, Frenchman Flat, and Yucca Flat drainage basins. Another major association is *Larrea-L. pallidum-Grayia* in south Jackass Flats, Rock Valley, west Mercury Valley, and southwest Frenchman Flat. Other associations are *Larrea-Atriplex-L. shockleyi* on the bajadas above southern Frenchman Flat extending to Ranger Mountain, *Grayia-L. andersonii* in the Yucca Flat basin, *L. pallidum-Grayia* in the southwest part of Frenchman Flat, and some *Coleogyne-L. andersonii* in areas between 1300 and 1600 m elevation in these basins. Beatley suggests that two different species of *L. pallidum* may be present, one being related to volcanic derived soils near Skull Mountain.

The *Lycium* species can be either dominant or associate species (Beatley, 1965). In the Rock Valley area the relative frequency of *L. pallidum* was around 10 and 0% and that of *L. andersonii* was from 18 to 25% (number of total shrubs of all species per hectare was 5586 and 4272) on two different 9-hectare plots (unpublished data of William Martin).

Figure 1. *Lycium pallidum* at the Nevada Test Site.

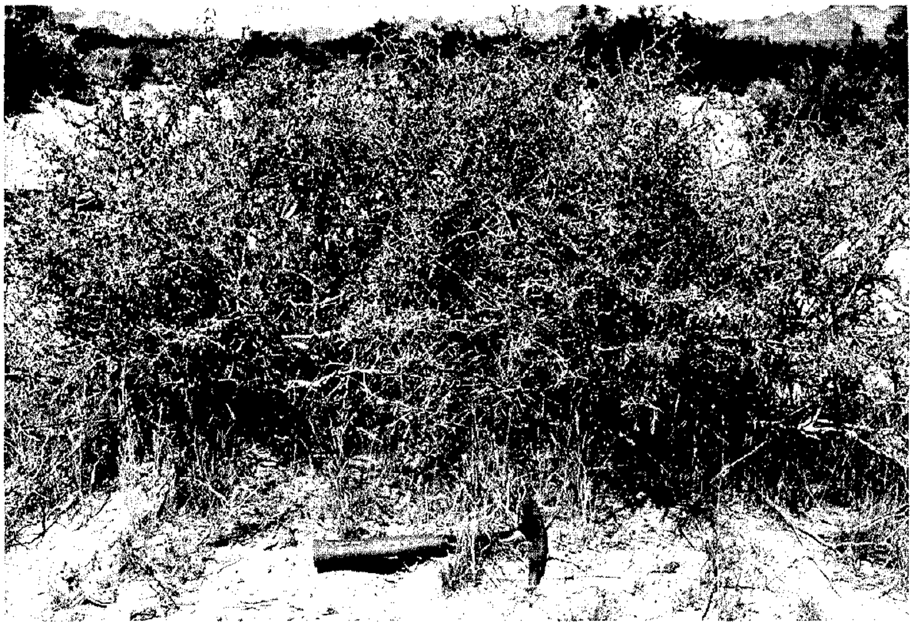


Figure 2. Lycium shockleyi at the Nevada Test Site.

Description

Shreve and Wiggins (1964) give the following description of Lycium:

Lycium andersonii A. Gray, Proc. Amer. Acad. 7:388, 1868, var. andersonii. A rounded shrub 0.5 - 3 m tall with spinose rigid branches and flexuous, light-barked twigs; spines numerous, slender, 5 - 20 mm long; leaves linear to linear-spatulate, 1 - 2 (3.5) mm wide, 3 - 16 mm long, rounded to acute at apex, gradually tapering to base, glabrous or slightly scurfy; pedicels 3 - 9 mm long, filiform; calyx shallowly campanulate, glabrous to sparsely puberulent, 1 - 2.5 mm long, 4 - 5-toothed, teeth about one-fourth as long as tube, sparsely ciliolate; corolla narrowly tubular-funnelform, 10 - 14 mm long, 1.5 - 3 mm wide at top, sordid-lavender, 4 - 5-lobed, lobes ovate, 1.5 - 2.5 mm long, ciliolate; stamens equaling corolla tube or exserted 2 - 3 mm; filaments adnate to basal one-third of corolla tube, sparsely pilose on lower part of free portion; style about equaling stamens; fruit ellipsoid or ovoid, 3 - 8 mm long, 2 - 5 mm wide, juicy, bright orange-red at maturity; seeds numerous.

Arid washes and stony or sandy slopes, mostly Lower Sonoran Zone, Colorado and Mojave Deserts, southern Nevada, and southern Utah to New Mexico and Arizona south through Sonora and Baja California, to northern Sinaloa. Also in Cuyama Valley, Santa Barbara County, California. (Feb.-May)

Lycium pallidum Miers, Ann. Mag. Nat. Hist. II, 14:131, 1854. A spreading, much-branched, spiny shrub 1 - 2 m tall with glabrous to sparsely pubescent, somewhat flexuous branches; bark smooth and lustrous when young, whitish; spines 5 - 10 mm long, slender; leaves ovate to oblong-spatulate, 3 - 15 mm wide, 1 - 4 cm long, acute or somewhat rounded at apex, tapering to a short petiole, glaucous, glabrous or nearly so; pedicels slender, 6 - 12 mm long; calyx shallowly campanulate, 5 - 8 mm long, 5-lobed, lobes ovate to lanceolate, acute, 3 - 5 mm long, glabrous and glaucous; corolla tube narrowly funnelform, 12 - 20 mm long, 5 - 6 mm broad at throat, greenish, tinged with purple, glabrous, 5 lobes oval to rhombic, 3 - 6 mm long, margins sparsely ciliolate; stamens exserted 3 - 12 mm, filaments adnate almost to middle of corolla tube, pilose below; style about equaling stamens; berry bright red, or blue-glaucescent, ovoid, 8 - 10 mm in diameter, 20 - 50-seeded.

Arid, sandy or rocky soil, Upper Sonoran Zone and higher parts of Lower Sonoran Zone, northern Arizona, southern Colorado, and western Texas south into Sonora, San Luis Potosí, and Zacatecas; mostly above the limits of the Sonoran Desert. (April-June)

Hitchcock (1932) gives the following description of L. shockleyi Gray, Proc. Amer. Acad. 22:311. 1837, which he refers to as L. cooperi Gray, Proc. Amer. Acad. 7:388. 1868.

A stout, spiny, densely branching, heavy shrub 0.7 - 2 m tall; branches thick and rigid, silver to purplish or tan when old, densely pubescent when young, spines short, thick, 3 - 10 mm long, blunt; leaves 3 - 10 in a fascicle, spatulate to obovate-spatulate or oblanceolate, 1 - 3 cm long, 0.4 - 1.0 cm broad, rounded to truncate at the apex, attenuate at base, glabrate to densely glandular-pubescent or hispidulous, midnerve and some of the lateral nerves usually evident; flowers numerous, 1 - 3 in a fascicle, borne on pedicels which are about same length as the calyx; calyx bowl-shaped or oblong-campanulate, 8 - 15 mm long, 1/3 - 2/3 as broad, glabrate, or much more commonly, glandular-hispidulous, lobes (4) 5, triangular to shortly ovate-lanceolate, from $\frac{1}{2}$ as long to about the length of the tube, expanding with the growth of the fruit and at length usually ruptured; corolla greenish-white with lavender veins, persistent until the ovary is well developed, tube 8 - 15 mm long, nearly cylindrical, slightly expanded at top, from densely pubescent to glabrous exteriorly, lobes (4) 5, 1/5 - 1/4 the length of the tube, ovate-triangular, rotate or reflexed, margins usually ciliate; stamens (4) 5, about equalling corolla-tube, or slightly included, filaments equal or subequal, adnate to near the middle of the corolla-tube, free bases of filaments and the vascular strands leading to them covered with long, spreading white hairs, anthers 1 mm long, or slightly longer; style about equalling stamens, or shorter than they; fruit 5 - 9 mm long, frequently 3-carpellary, ovoid, with a wedge-shaped apex, lateral constriction present somewhat above middle, forming 2 compartments nearly separated from one another, 1 (2) seeds in upper half, several (5 - 8) in lower, wall sclerenchymatous, especially in upper half, greenish-yellow.

Distribution: Mohave and Colorado Deserts of California, eastward to Yuma, Arizona, and northward to Esmeralda County, Nevada, and southwestern Utah.

Table 1. Mineral composition of leaves of *Lycium* species from the Nevada Test Site.

Location	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba	Li
	% of dry weight						ppm of dry weight												
L. andersonii																			
Mercury Valley	.15	.16	6.31	5.57	.96	.08	17.1	3	152	37	88	186	11	7.0	1.4	2.0	295	51	57
Frenchman Flat	.28	.10	7.11	5.58	1.11	.11	14.2	2	202	63	64	304	20	10.1	1.2	2.3	183	57	12
Near Sedan Crater	.23	.06	8.52	5.72	.77	.15	8.2	8	220	93	90	427	22	11.4	2.7	4.3	238	28	18
Rock Valley	.14	.20	3.77	5.77	.88	.17	19.4	3	255	27	63	460	33	6.7	2.7	4.1	341	49	176
L. pallidum																			
Rock Valley	.13	2.45	4.26	4.27	1.29	.20	10.8	4	249	124	60	473	35	6.6	.6	1.2	268	37	49
410 Road	.25	1.84	5.48	3.59	.92	.17	16.2	5	252	77	107	416	31	10.1	1.5	2.1	130	12	17
Specter Range south slope	.26	2.77	2.18	3.24	1.44	.18	14.5	4	267	110	100	417	51	9.6	.5	2.4	238	39	42
L. shockleyi																			
Frenchman Flat A	.30	4.23	3.42	1.77	.71	.16	12.2	3	203	45	50	415	15	2.3	.5	.5	47	24	10
Frenchman Flat B	.29	4.76	2.47	1.60	.69	.24	12.8	3	271	59	44	563	70	5.7	.5	.9	59	36	42

Observations

The Lycium species are winter dormant and leafless in the field during much of the year at the Nevada Test Site. The leafless condition begins actually in early summer when defoliation coincides with high temperatures and depletion of soil moisture. However, fruit (berries containing organic acids) mature before this time. New flush growth of leaves occurs usually in March but may begin in February depending on the seasonal climatic conditions. New leaves normally occur on established stems even in dry years, but new shoots generally are produced only in relatively moist growing seasons.

L. andersonii was in a second new flush in September 1967 following 5 to 10 cm of rain in various locations at the Nevada Test Site in July to September of that year. This followed a period of late summer dormancy. Occasional flowers appeared but no fruit was set. This is indicative of no chilling requirement to break dormancy in this species. L. pallidum was also in new flush in September and October of 1967, but less vigorously so than was L. andersonii; the new growth also appeared later than that on L. andersonii. It is possible that a small amount of chilling may improve new growth on this species. Relatively low soil temperature also is an important factor in the onset of new growth in L. pallidum.

A relatively large number of L. andersonii seedlings germinated in the late summer of 1967 and early spring of 1968 in certain areas of the Nevada Test Site, probably as the result of the 1967 summer rains. Germination occurred either in existing shrub clumps or out in open areas between shrub clumps. Shrub species that germinate in response to late summer rains in effect give them ten months without drought difficulty (Went, 1953). If germination occurs with winter and spring rains, summer drought may kill most of such seedlings because of relatively small undeveloped root systems. By germinating late in the year the new seedlings have the advantage of both winter and spring rains. Sufficient summer rain for germination may be available only in a very few years. Adaptive mechanisms to achieve summer germination also would need to include a fairly high temperature requirement for germination.

Jackrabbits cut off and eat woody portions of recently matured shoots as they do with other species.

Crowns of the Lycium may break up into several individual plants as shrubs advance in age. Adventitious shoots form readily on broken roots of L. andersonii (Figure 5). They actually formed on roots that were exposed to air without other injury when water washed the soil away from the root system. This root sprouting undoubtedly is a major means of reestablishment of the species. They behave this way too when grown in solution culture in the glasshouse.

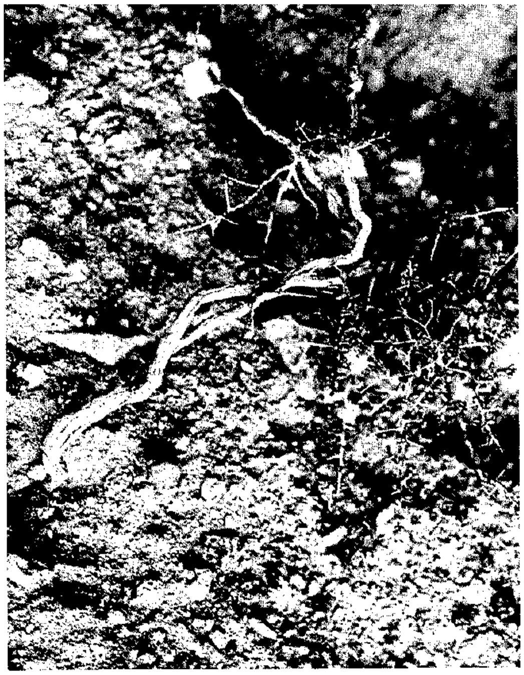
Experimental Results

Mineral composition of leaves of field-grown plants is given in Table 1. These three species differed in their sodium, potassium, and calcium contents which were, respectively, for L. andersonii, pallidum, and shockleyi approximately (Na) 0.2, 2, and 4; (K) 6, 4, and 3; and (Ca) 5, 4, and 2 as per cent of dry weight. These are relatively high cation contents. L. andersonii, the species lowest in sodium, was also highest in potassium and calcium. Zinc and copper contents were very low in these species.

No seedlings of L. andersonii germinated in the glasshouse from seed collections made in 1966 and 1967, and only 4 seedlings of L. pallidum germinated. On the other hand seed collections of both species made in 1968 and 1969 ger-

Figure 3. (left) Lycium andersonii at the Nevada Test Site.

Figure 4. Leaf forms of Lycium species growing at the Nevada Test Site (from left), L. shockleyi, L. pallidum, and L. andersonii.



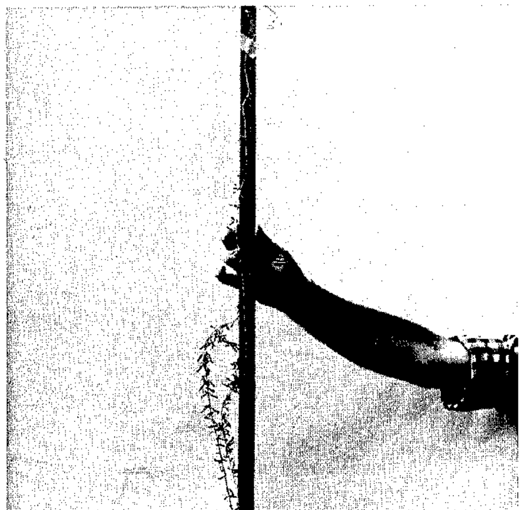


Figure 5. (top left) Adventitious shoots formed on L. andersonii roots which had been cut and exposed 2 years earlier by a trenching operation.

Figure 6. (top right) L. andersonii rooted cutting.

Figure 7. (bottom left) One-meter shoot on a L. andersonii cutting in the glasshouse in Yolo loam soil. The growth was a continuous flush.

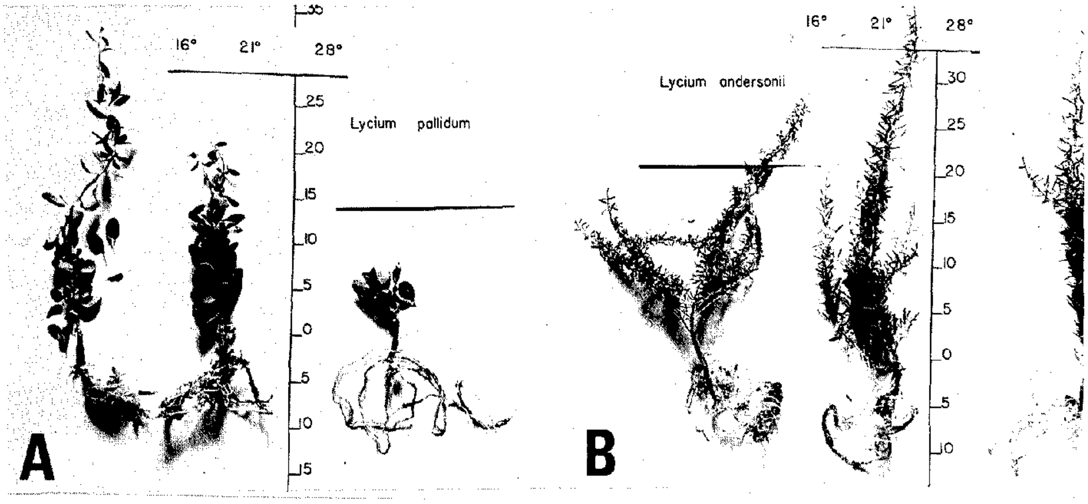
Figure 8. (bottom right) Root system of L. andersonii cutting in solution culture in the glasshouse.

minated readily in vermiculite without special treatment. Insect damage to seeds was evident in 1966 and in 1967, and this may be a far more important factor than the original seed viability or environmental conditions needed to break seed dormancy. *L. shockleyi* seeds collected in 1969 also germinated readily with no special treatment.

Cuttings of *L. andersonii* rooted readily (Figure 6). No special kind of plant material seemed necessary. Shoot pieces were dipped into Hormodin No. 2 powder (0.3% IBA in talc) and then they were placed into vermiculite in flats which were kept in a mist house until the stem pieces rooted. A large number of cuttings were made for various experiments. Rooted cuttings grow rapidly under glasshouse conditions. They may grow as much as 100 cm in a single flush (Figure 7) in contrast to the annual shoot growth in the field which may be no more than 1 - 5 cm. In solution culture root systems grow to large sizes (Figure 8). None of our cuttings grown in the glasshouse either in soil or in solution flowered until the night temperature of the glasshouse was raised to about 26°C. Fruits were set from this flowering.

L. andersonii plants grown in the glasshouse have much longer and larger leaves than those normally grown in the field. Glasshouse-grown leaves are long and flat, while those grown in the field are short and round (compare Figure 5 and 6). The unusually moist winter and spring growth season of 1969 produced longer, larger and more succulent leaves than normally occur in the field. This dimorphic leaf habit may explain subspecies description of *L. andersonii*. In the glasshouse, leaves abscise continuously and easily. Merely touching the plant causes some leaves to abscise. It would appear that ease of leaf abscission is a survival mechanism for this species. A hot dry wind could and does result in defoliation. One of the difficulties in measuring productivity of this species in the field is that the wind blows away so much of the foliage. In spite of ease of leaf abscission, the species is evergreen under the glasshouse condition. In the field under irrigation it approaches an evergreen condition depending upon the severity of winter.

Figure 9. A. Growth of *L. pallidum* seedlings in 60 days in relationship to root temperature. B. Growth of *L. andersonii* at different soil temperatures.



Cuttings from seedlings but not from old L. pallidum plants have rooted with different experimental conditions. Layering of stems from the seedlings has resulted in very little but in some rooting. Seedlings of L. pallidum do not do well in the glasshouse. Either soil or night air temperatures seemed to be involved. After an initial vigorous growth, the seedlings usually stand without growing. Placing seedlings in the refrigerator for 17 days at about 5°C did result in subsequent new growth following defoliation from the cold treatment, but the vigor was short lived. A study of soil temperature indicated that our problem was one of soil temperature being too high. Seedlings in Figure 9 were grown two months at different soil temperatures. Near 16° C seemed to be the optimum soil temperature. Leaves of the juvenile plants in the glasshouse are large. It is of interest to note that on a mature plant severely injured by truck wheels in the field, new shoot growth was a juvenile form like that of the glasshouse seedlings.

Growth of L. andersonii appears to be independent of soil temperature (Figure 9B), but not of soil pH when cuttings were grown for 90 days in Yolo loam soil that had been amended with 10% $CaCO_3$ or with 2% sulfur to give soil of different pH. Acidification resulted in decreased dry weight and $CaCO_3$ did to a lesser extent. The micronutrient composition was related to soil pH (Table 2). Boron and molybdenum decreased with decreasing pH as did calcium. Copper, zinc, and manganese increased with decreasing pH, and their content was greater than normally occurs for field-grown plants (soil was highly calcareous in the field). Lithium was high enough to detect in the leaves of these plants which is different from most other plants studied from the Nevada Test Site. Strontium values were also higher than for some other species, and this in part may be due to high calcium contents.

Table 2. Shoot yields and mineral composition on the dry weight basis of leaves of L. andersonii grown in Yolo loam soil with and without excess $CaCO_3$ and sulfur.

Measurement	$CaCO_3$ (pH 7.5)	Control (pH 6.0)	Sulfur (pH 4.2)
Leaf wt, g/plant	1.89	2.48	1.39
Stem wt, g/plant	6.18	8.31	4.11
Ca, %	2.24	1.83	1.03
K, %	6.66	6.15	9.70
Mg, %	.60	.55	.56
Na, %	>.20	>.20	>.20
P, %	.25	.42	.49
B, ppm	61	59	33
Cu, ppm	16	18	57
Fe, ppm	99	90	100
Mn, ppm	103	148	534
Co, ppm	T	T	0.6
Mo, ppm	25.3	9.5	3.3
Zn, ppm	15	15	35

Means of determinations from 3 plants.

Lycium andersonii cuttings previously in soil were bare rooted and grown in solution culture for 39 days with one solution renewal at 20 days. A full description of treatments is on page 177; similar treatments were used for some

Table 3. Mineral composition of *L. andersonii* grown in solution culture with different nutrient treatments.

Treatment*	Yield g	N %	P %	Na %	K %	Ca %	Mg %	Zn ppm	Cu ppm	Fe ppm	Mn ppm	B ppm	Al ppm	Co ppm	Mo ppm	Pb ppm	Sr ppm	Ba ppm
							Leaves											
Control	6.99	3.99	0.66	0.20	9.99	1.89	0.44	13	3	67	86	54	11	0.2	16	0.5	4	4
1/20 P	6.41	3.55	0.12	0.20	8.92	1.45	0.43	19	6	63	99	25	15	0.2	13	0.5	3	4
-Fe	0.86	4.16	0.79	0.08	8.09	2.15	0.60	97	5	27	335	131	24	0.2	13	0.5	5	4
1/20 K	3.84	5.04	0.82	0.20	1.14	3.31	0.58	5	5	85	134	88	16	0.2	17	0.5	8	4
1/10 N	2.13	1.58	1.15	0.20	9.99	2.63	0.42	200	16	44	201	26	23	0.2	27	3.1	14	7
-Zn	5.54	4.71	0.87	0.20	9.99	1.98	0.39	10	4	81	98	49	27	0.2	13	0.5	4	3
1/10 Mg	5.19	4.67	0.55	0.20	9.99	1.63	0.13	23	5	43	95	48	12	0.2	14	2.0	3	3
.005N Na	5.70	4.90	1.30	1.22	9.72	1.89	0.35	30	6	55	100	40	10	0.2	16	0.5	4	3
							Stems											
Control	6.42	2.07	0.28	0.01	1.30	0.70	0.13	49	5	15	29	12	3	1.6	1.4	0.9	3	2
1/20 P	7.30	1.81	0.13	0.02	1.39	0.59	0.13	44	11	20	35	9	5	2.4	1.5	1.6	2	2
-Fe	1.44	1.62	0.27	0.01	1.56	0.69	0.14	106	8	10	72	19	6	0.9	1.4	0.9	3	2
1/20 K	4.04	1.61	0.28	0.05	1.11	0.62	0.13	68	7	11	34	10	6	1.7	1.9	8.4	2	1
1/10 N	1.51	1.05	0.36	0.04	2.60	0.50	0.12	99	13	150	57	16	7	1.0	4.7	4.0	5	7
-Zn	5.43	2.28	0.31	0.03	1.60	0.64	0.15	30	6	26	42	14	5	1.7	2.1	4.0	2	1
1/10 Mg	3.52	2.23	0.31	0.01	1.46	0.73	0.10	52	5	14	36	15	3	1.2	2.1	1.2	3	1
.005N Na	5.90	2.11	0.30	0.07	1.68	0.57	0.12	68	9	16	39	12	3	1.5	1.4	1.6	2	1
							Roots											
Control	6.12	2.85	0.70	0.13	3.19	0.44	0.26	94	8	285	43	37	13	1.0	6	1.8	3	7
1/20 P	5.44	3.86	0.18	0.14	2.73	0.33	0.14	93	7	175	36	25	35	1.4	7	1.8	3	6
-Fe	1.04	4.85	0.69	0.03	6.21	0.71	0.26	200	14	265	202	74	208	1.4	40	7.9	4	5
1/20 K	2.78	3.71	0.90	0.20	1.13	0.41	0.29	169	15	1045	58	35	117	3.6	9	4.7	3	24
1/10 N	2.52	1.61	0.30	0.03	1.80	0.40	0.09	57	10	62	41	30	6	2.3	2	1.6	4	3
-Zn	3.11	3.54	1.13	0.20	3.07	0.36	0.18	86	15	1318	178	40	570	6.5	8	12.1	3	14
1/10 Mg	3.44	4.34	0.74	0.08	4.58	0.44	0.10	154	10	701	71	42	13	1.7	8	10.4	3	10
.005N Na	4.38	3.79	0.91	1.26	4.18	0.36	0.27	142	12	825	61	41	190	2.3	7	12.8	3	32

*Except for treatments indicated, plants received a complete nutrient solution. Values are on the dry weight basis.

other plants. The results are in Table 3. The low phosphorus treatment resulted in greatly depressed phosphorus content of plants but not in decreased yields. The species may have a low phosphorus requirement. A level of phosphorus of 0.12% of dry weight is above the critical level of phosphorus. The 0.2% of dry weight for field-grown *L. andersonii* from the Nevada Test Site (Table 1) must also be above the critical level. A leaf nitrogen level of 1.58% of dry weight was limiting when grown in solution culture and this compares with about 1% for plants in the field. A leaf iron content of 27 ppm of dry weight was limiting; a leaf potassium content of 1.14% was limiting; a leaf magnesium content of 0.13% might have been limiting. The micronutrient contents of the plants were of great interest and merit further study. Of interest was the steep gradient in zinc content from leaves to stems to roots.

Growth of *L. pallidum* seedlings was more related to soil temperature than was growth with *L. andersonii* (Figure 4). *L. pallidum* is dormant during summer months and responds somewhat to late summer rains, but not as vigorously as does *L. andersonii*. The effect is most likely related to soil temperature. Mineral composition of the *Lycium* species grown at different root temperatures appears in Table 4. Sodium content was slightly lower and potassium and calcium were higher for *L. andersonii* than for *L. pallidum* corresponding to the field plants (Table 1). Zinc and copper contents were much higher for these plants grown in slightly acid soil compared with the field ones grown in highly calcareous soil. Copper and molybdenum contents of both species increased with temperature; but aluminum, boron, and manganese be-

Table 4. Mineral composition of leaves of *L. andersonii* and *L. pallidum* grown 60 days in Yolo loam soil at different root temperatures.

Temp °C	Dry wt g	P	Na	K	Ca	Mg	Si
				% dry weight			
			L. andersonii				
16	3.11	0.91	0.68	6.27	3.95	1.16	0.59
21	3.48	0.34	0.84	6.91	4.60	0.84	0.17
28	3.40	0.26	1.18	6.64	4.67	0.82	0.15
			L. pallidum				
16	4.30	0.25	2.02	5.18	2.99	1.48	0.07
21	3.05	0.25	1.59	5.61	1.57	0.93	0.06
28	1.58	0.32	0.79	6.68	2.21	1.17	0.15

Temp °C	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba	Li
						ppm dry weight							
						L. andersonii							
16	59	9	407	183	77	1540	373	5.9	2.9	11.3	114	256	17
21	36	26	340	60	95	534	41	10.4	1.3	2.6	118	222	35
28	25	11	293	54	93	448	62	11.0	2.6	4.3	112	229	93
						L. pallidum							
16	123	9	195	19	201	152	5	8.2	0.5	1.8	80	108	94
21	56	14	127	125	74	67	3	15.5	0.8	1.4	45	56	133
28	51	47	210	159	81	316	31	24.9	2.2	4.2	68	108	154

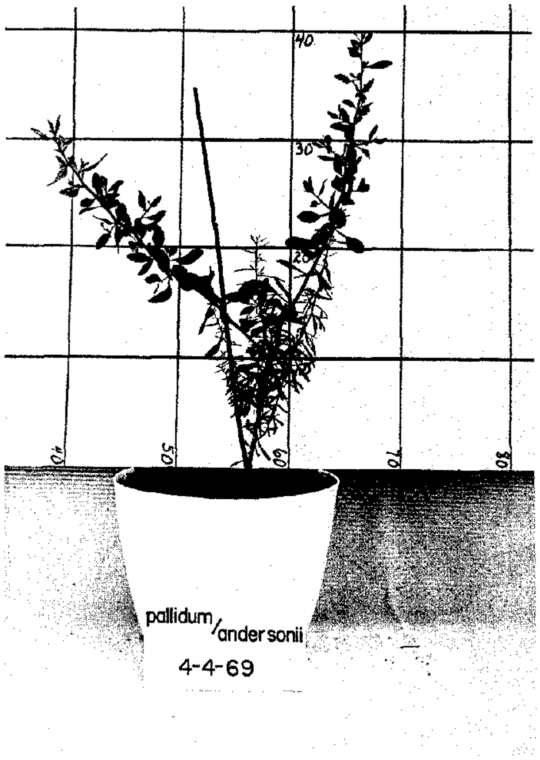


Figure 10. (left) Response of L. andersonii to ionizing radiation. Control, left and 8 kR, right. The root was shielded with 5 cm of lead and as a result new shoots are growing from the base.

Figure 11. (right) Grafting of L. pallidum on L. andersonii.

haved differently for each species. Both species appeared to accumulate lithium and the accumulation increased with root temperature.

L. andersonii is much more sensitive to ionizing radiation than are some other shrub species with which it is associated. It has a high nuclear and somatic interphase chromosome volume (Nuc. vol. = 466 μ^3; ICV = 9.7 μ^3). Shoots died and leaves abscised in 2 to 3 days on rooted cuttings exposed to more than 4 kR gamma radiation from a ^{60}Co source. When the roots were protected with lead shielding, new growth developed from the base of shoots irradiated at levels as high as 100 kR. Figure 10 shows how the dose rate of 8 kR with roots shielded with 5 cm lead resulted in death of original shoots and new shoots grew from the base of the plant.

Grafting compatibility has been demonstrated between L. andersonii and L. pallidum (Figure 11).

Mineral element composition of L. andersonii leaves and stems on a seasonal basis is given in Table 5. Several of the mineral elements increased with age of leaves (calcium, magnesium, silicon, iron, boron, aluminum, molybdenum, and perhaps strontium and barium). Phosphorus and manganese decreased with age. Stem materials less consistently indicated the aging process.

Summary

Lycium andersonii, Lycium pallidum, and Lycium shockleyi appear to have different soil requirements. Lycium species are winter dormant and leaf-

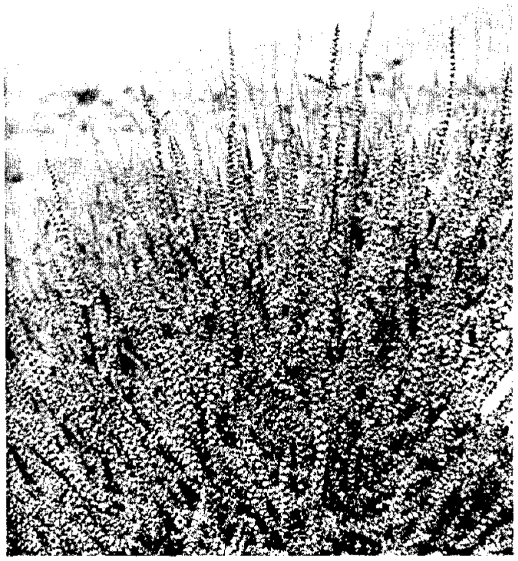
Table 5. Seasonal mineral contents (1969) – *Lycium andersonii* (dry weight basis).

Sampling date	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Co	Ni	Mo	Sr	Ba
			%										ppm					
								Leaf tissue										
17 Mar	.51	.004	1.57	4.01	0.39	.06	58	17	175	91	57	173	9	1.8	3.4	T	49	11
4 Apr	.18	.009	3.19	6.36	1.21	.06	62	8	192	33	70	184	11	1.0	1.4	3.4	78	12
21 May	.04	.006	3.21	10.82	1.47	.07	44	6	142	24	118	128	9	2.7	4.1	5.7	67	24
19 June	.03	.008	2.17	11.51	2.21	.12	46	11	242	21	123	362	22	2.1	2.7	5.8	76	26
								Stem tissue										
11 Feb	.04	.001	0.46	2.59	0.06	.10	32	14	322	12	11	341	13	T	0.8	T	62	6
17 Mar	.04	.002	0.65	1.52	0.06	.07	17	13	149	11	12	221	9	T	1.8	2.0	46	6
4 Apr	.07	.004	1.11	1.84	0.14	.05	40	27	111	12	18	277	6	T	1.7	2.0	52	7
21 May	.09	.002	1.27	1.32	0.16	.05	42	25	177	4	17	138	14	T	T	1.5	54	7
19 June	.05	.001	1.01	1.52	0.15	.03	38	30	149	6	13	92	3	T	T	1.0	47	6
29 July	.06	.002	1.02	1.24	0.10	.03	25	23	69	7	9	77	5	T	T	1.0	47	6
24 Sept	.04	.003	0.51	2.24	0.09	.10	45	30	328	12	14	285	14	T	1.4	T	56	6
31 Dec	.09	.020	0.77	2.27	0.16	.32	30	15	247	16	26	314	12	1.1	2.5	0.8	54	18

less because of extremes in soil moisture and soil temperature. Adventitious shoots form on roots of *L. andersonii* and cuttings of this species root readily. Seedlings of *L. andersonii* and *L. pallidum* germinate readily in the glasshouse when viable seed is obtained. Cuttings of *L. pallidum* seedlings have rooted; but some individual plants have been propagated by layering. Glasshouse-grown leaves of *L. andersonii* and *L. pallidum* are much different from those grown in the field. The ease of leaf drop in *L. andersonii* mav be a survival mechanism. Shoots of rooted cuttings of *L. andersonii* grow several feet in a single flush in the glasshouse compared with a few cm in the field. *L. pallidum* grows poorly in the glasshouse unless soil temperature is low, at least initially. Growth of *L. pallidum* appears to be dependent upon soil temperature while *L. andersonii* does not. The mineral composition of *L. andersonii* is characterized by high calcium and potassium and low sodium and zinc contents. *L. pallidum* and *L. shockleyi* have lower calcium and potassium and higher sodium contents than *L. andersonii*. *Lycium* species appear to accumulate lithium. *L. andersonii* appears to have a low phosphorus requirement. *L. andersonii* is highly sensitive to ionizing radiation in relation to other shrub plant species found at the Nevada Test Site and it has a high nuclear volume. Grafting compatibility occurs between *L. andersonii* and *L. pallidum*.

CHARACTERISTICS OF SALSOLA SPECIES

Salsola is considered as a late summer annual. Two separate species of Salsola seem to be present at the Nevada Test Site. Previously all Salsola



Figures 1 & 2. Field-grown mature S. pestifera (top) and S. paulsenii.

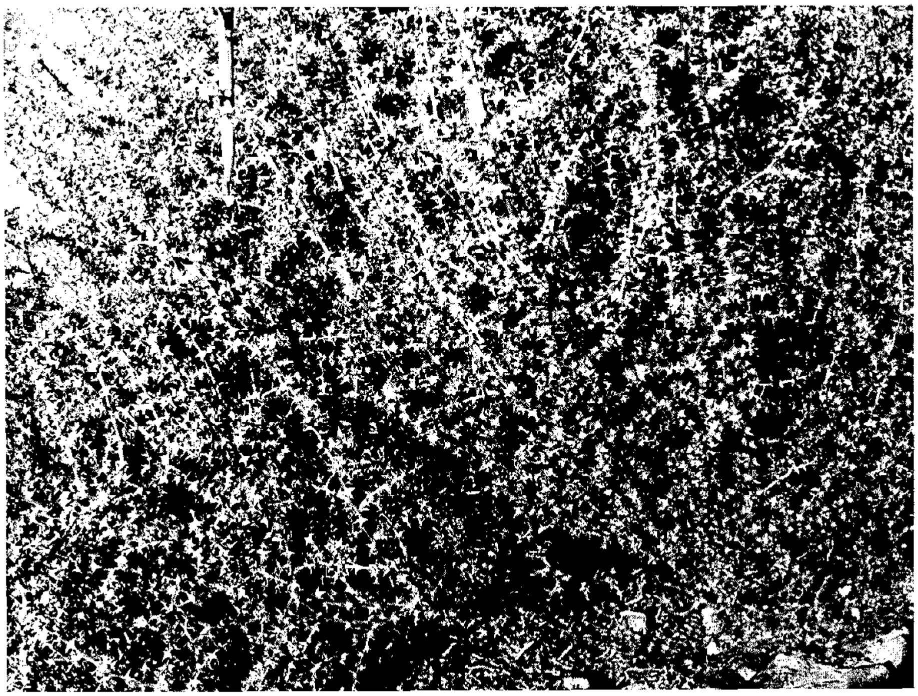
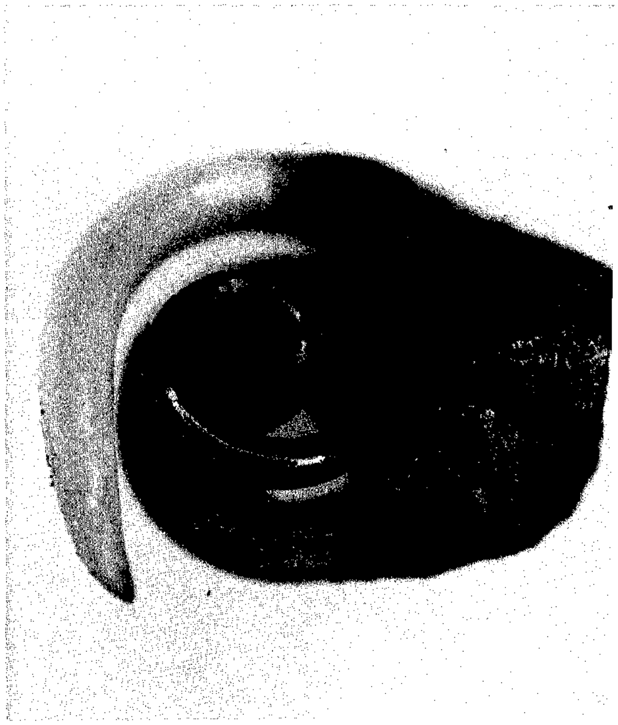


Figure 3. Salsola pestifera seed upon adding water.

Figure 4. Salsola seeds 38 minutes after wetting.



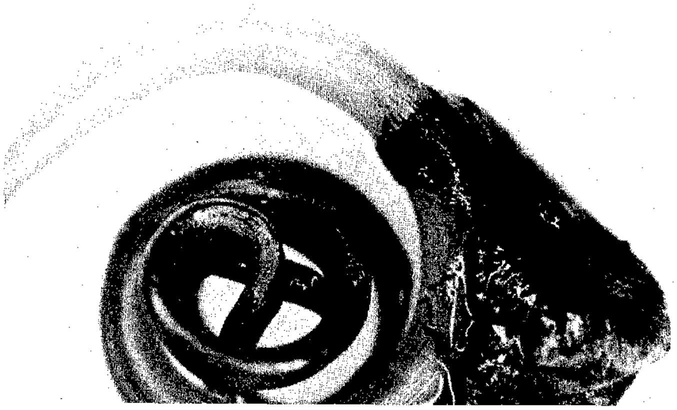


Figure 5. Salsola seeds 61 minutes after wetting.

there was considered to be S. kali and some of the sections of this report indicate this nomenclature. One, Salsola pestifera (Figure 1), is generally larger, less spiney, more open than the other one, and Salsola paulsenii is smaller, compact, and more thorny (Figure 2) (Beatley, 1969). These two species evidently hybridize and the characteristics of S. pestifera seem to be dominant on approximately a 3:1 segregating basis. S. paulsenii appears to occur in some places in almost pure stands, however.

The tumbleweed, Salsola genus, commonly known as Russian thistle, is an introduced plant into the United States. As a pest, it causes fire hazards, obstructs roads and streams, and is a host plant for insects and curly-top virus involving many crops. It grows extremely well under semiarid conditions. It has produced 1500 - 1800 kg per hectare of seed under about 20 cm of rainfall (Coxworth et al., 1969). In dust bowl days in the U.S.A. Midwest during the 1930's when there was insufficient rainfall for regular crops, farmers harvested it as a forage crop. It needs only one-third to one-half the water required to produce a dry-matter unit as does alfalfa (Stevens, 1943).

Salsola seeds contain no endosperm. They have a spiral embryo which contains some chlorophyll in the seed stage. At temperatures above about 11° C the seeds germinate when in contact with moderately moist soil. Some other plant species do germinate at lower soil moisture, however (see page 279).

At temperatures above about 28°C the seeds germinate literally in a matter of minutes (Figures 3 - 5), if sufficient moisture is present.

Germination consists of unwinding of the spiral embryo and also of elongation of the cells of both the embryo and the root (radicle). The spiral action of the unwinding embryo forces the root into soil if the soil is loose and pliable which is often the case when soil has been disturbed. These characteristics allow successful germination of the seed with a very small amount of water. Other species are reported to have a similar action which results in survival (Negbi et al., 1961, 1963).

Tests with sufficient gamma radiation to stop cell division but not enough to stop germination (Figure 6) suggest that germination is wholly a matter of rapid cell elongation when sufficient moisture is present at a proper temperature (Wallace et al., 1968). A bimodal response is obtained when seed are irradiated and then germinated. Exposure of up to about 60 kR with a ^{60}Co source resulted in no apparent effect in germination or growth of the seedlings. Exposure to between 60 and 400 kR resulted in germination and elongation of shoots and roots to a certain limit only. Exposures above 500 kR resulted in progressively less elongation and in death of seedlings. The first response curve obviously relates to cell division. The implication is that the seed contains the fully differentiated seedling which grows by cell elongation when exposed to water at the proper temperature. No cell division is needed for this phase of growth; hence there is no effect of the radiation at levels which inhibit nucleic acid synthesis and function (Kohn et al., 1967; Nakao et al., 1967). When the level of radiation is sufficient to inhibit nucleic acid synthesis, the seedlings are inhibited in their growth. When the level of radiation is sufficient to cause enzyme failure (over 500 kR) (Ku and Romani, 1966; Romani, 1964, 1966; Romani and Fisher, 1966; Romani et al., 1966; Romani and Yu, 1966, 1968; Somogyi and Romani, 1964) a second response curve is obtained and death of seedlings follows. Figure 6 indicates these responses.

Salsola species do not grow on undisturbed natural terrain unless moisture is satisfactorily favorable. Seeds germinating on the surface of hard soil become dehydrated and die because their roots cannot penetrate such a surface. For this reason Salsola species are usually not seen on deserts unless the soil has been disturbed On disturbed desert soils, it grows extremely well under the somewhat limiting moisture conditions which prevail. It also grows well on areas on which woody shrubs have been killed because of the more favorable water balance. Germination characteristics of other species of Salsola have been described by Negbi and Evenari (1961).

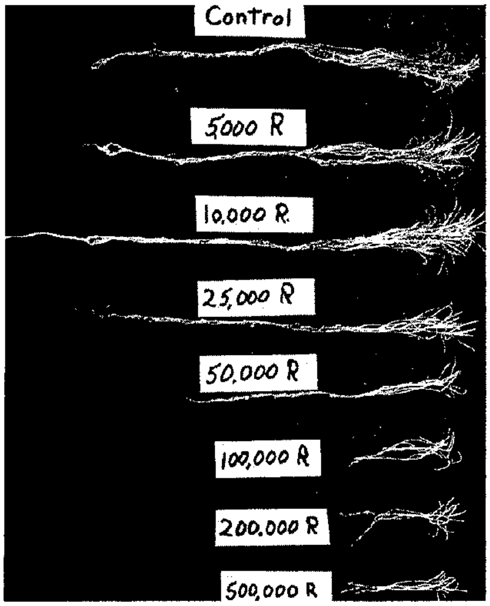


Figure 6. Results of irradiating seeds with different levels of ^{60}Co radiation. Cell division appears impaired between 25 kR and 100 kR. Above 100 kR cell elongation without cell division appears to occur. Seeds fail to germinate at about 1000 kR.

Salsola is a dominating genus invading disturbed areas at the Nevada Test Site. A typical scene is shown in Figure 7. Salsola species do not always appear in the disturbed areas for one or two years particularly in remote areas and this is believed to be due to the relative unavailability of seed. Salsola species are most apt to invade where the soil has been disturbed but soil disturbance is not absolutely necessary for such invasion. Death of existing plants as sometimes happens with radiation (Rhoads et al., 1969) results in Salsola species invasion. The absence of the other plants results in a more favorable soil moisture situation although the possibility of allelopathy must be considered (see page 310). Even though Salsola species are adapted for rapid root entry into disturbed soil, the availability of moisture is probably even more important to its becoming established.

Salsola pestifera transpired less water per gram of new growth or per gram dry weight at a soil temperature of 29°C than one at 13°C when soil moisture was limiting (Wallace, 1970). Evidently it has increased resistance to water loss when soil temperature gets high. This too can be an adaptive survival mechanism. Transpirational water loss per unit of new growth was greater at 20°C than at 13°C, however, when soil moisture was not limiting.

Salsola species are extremely resistant to ionizing radiation particularly

Figure 7. Invasion of Salsola species at a site where native vegetation has been killed and the soil surface disturbed.

for seeds (see page 50). It has a relatively low nuclear volume. Radiation has relatively little effect on established plants for levels up to 10 kR.

S. pestifera appeared to be a species that fixes carbon dioxide by the C-4-dicarboxylic acid pathway (Hatch and Slack, 1966, 1970). This pathway, accompanied by low photorespiration (Hatch and Slack, 1966, 1970; Egle and Fock, 1969; Tregunna et al., 1969), leads to greater percentage utilization of the carbon dioxide of the air, i.e., to a lower compensation point (see page 322).

The relative fixation for the PEP carboxylase system extracted from S. pestifera was 1.31 μmoles per unit of fresh weight vs 0.48 μmoles by the carboxydismutase system. This ratio is highly indicative of the C-4-dicarboxylic acid pathway. Plants that use this pathway are highly efficient in terms of photosynthesis and have great competing power (Black et al., 1969). The biomass production of Salsola at the Nevada Test Site varies from zero to over 500 kg dry matter per hectare under different conditions. Under irrigation it has been 15,100 kg per hectare. This is from 30 to hundreds of times the biomass production of winter annuals at the Nevada Test Site (Beatley, 1969). Biomass production and the photosynthetic pathway do seem to be related. The adaptation makes it possible for the species to grow vigorously during the period in which soil moisture is available.

Summary

Salsola species are abundant at the Nevada Test Site especially where soil has been disturbed or where the native vegetation has been killed which results in a more favorable water balance. The species appear to have several adaptive mechanisms which result in its survival under arid conditions. These include rapid germination and penetration into soil, increased resistance to water loss through transpiration as soil temperature increases, and high photosynthetic efficiency through the C-4 dicarboxylic fixation pathway. Salsola is very resistant to ionizing radiation.

Note

Excerpts from a letter from V. Botschantzev to Dr. William A. Weber and to us through the courtesy of Dr. Janice Beatley clarifies some of the questions concerning nomenclature of Salsola. The letter was received after these reports were prepared.

> Unfortunately I have not finished examining the species group of the genus Salsola you are interested in, therefore my determinations of your plants, are, to some extent, preliminary.
>
> Your specimens have considerably smaller flowers as the specimens of the same species which grow in our country. Still, I think, that you may identify your plants as belonging to the same species, because your specimens are apparently only local modifications of this Salsola species.
>
> I think, that it will be correct, if I distribute your plants in accordance with the maximum resemblance along two species:
>
> Salsola paulsenii Litv. 9753, 9754, 9756, 9762
> Salsola iberica Sennen et Pau 9755, 9757, 9800
>
> The second species has the name S. iberica, because this name was published in 1908 and the other names—its synonyms—were published later (S. pestifera in 1909, S. ruthenica Iljin in 1934 etc.)
>
> V. Botschantzev
> Leningrad, Sept. 23, 1970

CHARACTERISTICS OF FRANSERIA DUMOSA
(BURRO BUSH OR BURR SAGE)

Franseria dumosa Gray (Burro bush or Burr sage) (see Figure 1) is commonly found with *Larrea divaricata*, but occasionally may occur as an almost pure stand (Beatley, 1965). *F. dumosa* is a good shrub for grazing or browsing. It is deciduous, being mostly leafless in late summer (if there are no summer rains) and in winter. It, like *Lycium andersonii*, easily abscises leaves, often on touch, and this likely is a survival mechanism which prevents excessive water loss from hot dry winds.

F. dumosa is confined to relatively warm areas and its northern range at the Nevada Test Site is in Yucca Flat (Beatley, 1965, 1969). It does not grow at the higher elevations of the Nevada Test Site.

Shreve and Wiggins (1964) describe *F. dumosa*:

> A much-branched, rounded, shrubby perennial 2 - 6 dm tall; branches stiff, more or less spinose, densely strigillose-canescent when young, eventually glabrate; bark gray and slightly striate-fissured; leaves ovate in outline, 0.8 - 2 cm long, pinnately to bipinnately divided into short, rounded or obtuse lobes 0.5 - 2 mm wide, 0.5 - 3 mm long, often having a lacelike appearance, densely grayish-tomentose on both sides; petioles 2 - 20 mm long; inflorescences racemose or spiciform, staminate and pistillate heads often intermingled throughout length of racemes; staminate heads on peduncles 0.2 - 3 mm long; involucres broadly saucer-shaped, 4 - 5 mm wide, strigillose-canescent, lobes 5 - 8, broadly triangular-ovate; nearly as long as wide; receptacular paleae linear, with dilated rhombic-spatulate tips, finely villous; corollas puberulent, yellow; pistillate heads 2-flowered; fruit 4 - 5.5 mm long, subglobose, moderately glandular-puberulent, beaks 2, conic-subulate, straight, 1 - 1.5 mm long; spines 30 - 40, narrowly subulate, flattened toward base, 1.5 - 2.2 mm long, tips not hooked.

Figure 1. Typical mature *F. dumosa* shrub growing at the Nevada Test Site.

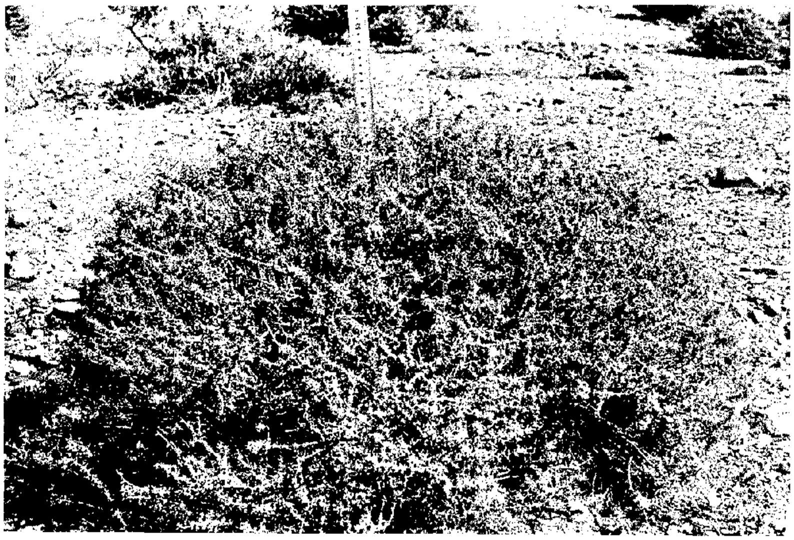


Figure 2. New seedlings of F. dumosa germinate under or near existing shrubs or in open areas. Survival depends upon an extended seasonal moisture supply.

Arid plains, mesas, outwash slopes, and arroyos, Lower Sonoran Zone, Mojave and Colorado Deserts, California, through southern Nevada into southern Utah, south into northern Sonora and along the eastern side of Baja California to the Sierra de la Giganta and the southern part of the Magdalena Plain. Occasionally ascending to 6,000 feet on dry ridges. Feb.-Dec.

F. dumosa develops new leaves relatively early in the spring. Those plants growing near an artificial stream of waste water from a sewage processing plant had green leaves essentially year around, and they responded favorably to water by producing more than the normal amount of new shoots and succulent foliage. No particular chilling or photoperiod requirements seem necessary for this species. July to September rains in 1967 (5 to 10 cm) resulted in new leaves, flowers, and mature seeds—the second crop of seeds for the year. All individuals, however, did not respond to the rains. Several ecotypes seem to be involved. This type of behavior would result in two growth rings for that particular year. The seed maturing in the late fall in 1967 was viable, as was seed produced any time of the year in the glasshouse or in the open at UCLA.

F. dumosa shrubs have more annual plants growing around them than most shrub species (Muller, 1953). This seems to indicate a lack of allelopathic substances produced by this shrub.

Seeds of F. dumosa germinate readily with no special precautions. Glasshouse grown plants grow readily in soil and in nutrient solution. Flowers are produced in the first season on seedlings grown in the glasshouse and the species produces flowers and set seeds in any season of the year. It therefore has no special photoperiod requirements.

A large number of seedling plants occur at the field study sites (Figure 2), sufficient to maintain the present population if survival were from 5 to 10 years. It would appear that the average age of F. dumosa is not great in the Nevada Test Site area. The number of growth rings in the stem-root crown section of several mature plants examined varied from 15 to 25 and there easily could be two rings formed during some years as occurred in 1967. Considerable dieback of shoots occurs in this rather compact and dense shrub. Stem wood deteriorates rapidly and is wind-pruned easily, which allows space for new shoots to develop. New shoots are produced only after a relatively wet winter season; new leaves form on existing stem wood, but the size of leaf developed is dependent upon the amount of available soil moisture. The juvenile form of large, succulent leaf is generally produced on new shoots rather than on existing stem wood.

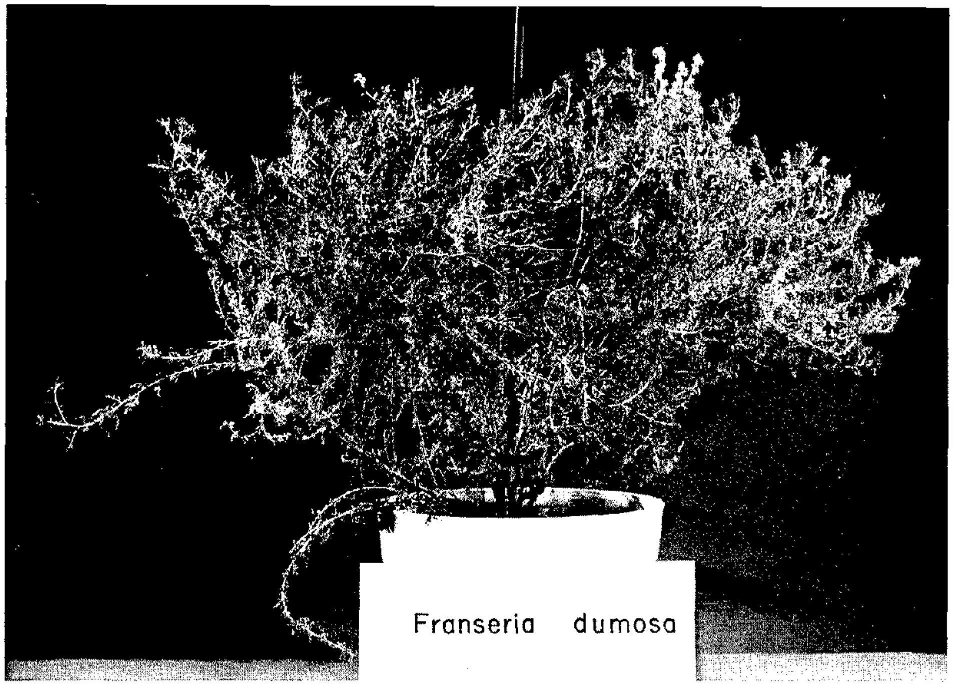


Figure 3. Rooted *F. dumosa* cutting about 6 months old. A similar sized shrub growing in the field would be 3 to 5 years old.

F. dumosa shrubs in full leaf flush in a wet stream area in January 1968 were severely injured because of a freeze of about -10°C. Shrubs in dry areas not in growth flush were not injured. This effect was repeated again in 1969 and 1970. Even though many other shrub species grew vigorously in the spring of 1969 following unusually heavy early spring rainfall, *F. dumosa* did not. This supposedly resulted from continued cold weather and frost injury. New *F. dumosa* seedlings became plentiful in the growth season following these spring rains, but many of them have not survived the very dry fall, winter and spring seasons of 1970. A very marked increase in new seedling survival has, however, occurred in the study plots under sprinkler irrigation near Mercury and in wet stream areas.

Experimental Results

In addition to ease of germination, *F. dumosa* also is easy to root from cuttings. The procedure involves dipping the cuttings in Hormodin No. 2 (0.3% IBA in talc) and putting them in vermiculite in a mist or fog house until they are rooted (Figure 3). Chase and Strain (1966) also reported that *F. dumosa* is easy to root. Of the several different shrub species we have studied from the Nevada Test Site, the juvenile *F. dumosa* grows most rapidly in artificial environments.

On February 6, 1967, approximately one-month-old seedlings of several plant species were transplanted along the edge of a glass-fronted metal case which was some 50 cm deep. A cover over the glass front was removed periodically to observe the rate of vertical penetration of the roots. The taproot of a seedling of *F. dumosa* elongated 32 cm in 19 days and had one of the deepest and most rapid rates of root growth of the species studied. This obviously is a survival mechanism and may account for the large number of seedlings

[redacted]

Table 1. Yield and mineral content of *F. dumosa* grown in Yolo loam soil for 60 days at varied soil temperatures.

Soil temp. °C	Dry wt mg/plant	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Mo	Sr	Ba
		% of dry weight					ppm of dry weight							
10	680	.53	.20	5.99	1.86	.61	93	32	102	137	314	3.1	50	60
21	1030	.39	.20	5.72	.93	.39	78	21	207	132	209	4.6	35	56
37	1280	.45	.20	6.50	1.75	.44	77	25	115	209	285	7.8	45	68

Table 3. Mineral composition of leaves of *F. dumosa* from various locations at the Nevada Test Site.

Location	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
	% of dry weight						ppm of dry weight											
Mercury Valley A	.48	.10	4.78	2.49	.59	.26	14	5	331	44	180	647	70	2.2	0.6	1.5	76	21
Mercury Valley B	.41	.18	5.39	3.18	.61	.41	>13	4	436	64	188	905	54	2.7	1.6	2.5	156	39
Rock Valley A	.35	.10	4.91	3.02	.53	.25	>11	3	258	57	146	575	26	21.8	1.4	2.8	126	23
Rock Valley B	.30	.06	3.82	3.78	.46	.24	45	23	357	61	215	526	32	3.7	2.1	2.9	82	15
Frenchman Flat A	.37	.04	3.57	1.83	.34	.15	30	7	209	23	81	307	12	2.3	1.0	1.0	22	7
Frenchman Flat B	.32	.12	5.21	1.91	.49	.25	10	8	259	79	183	404	14	4.8	1.0	9.4	46	8
Lathrop Wells	.25	.10	3.40	2.66	.42	.20	25	10	166	34	362	554	36	2.1	2.7	1.0	184	27
40 mile Canyon	.33	.10	3.34	3.07	.55	.35	23	5	367	189	222	819	52	4.1	0.9	9.4	79	23
Indian Springs	.46	.11	3.80	1.48	.72	.23	25	9	284	47	259	458	21	4.2	2.1	5.4	87	21

which survive in the field.

Cuttings or seedlings growing in potted soil in the glasshouse easily wilt when soil moisture becomes limiting. It appears that the tendency to wilt is much more pronounced with glasshouse-grown plants than in the field, indicating that some kind of preconditioning is necessary to induce the drought resistance encountered in the field. The leaves tend to abscise from F. dumosa upon wilting when the soil moisture is decreased to about 3% of dry weight. If soil moisture is maintained slightly above the wilting point, the shrub will produce a small rosette-type of leaf on existing stem wood but no new shoots or succulent leaf forms are produced.

F. dumosa responds to soil temperature (Figure 4). Shoot growth of young plants was greater at 20° C than at 33° C. It was lowest at 11° C. In another study, greater growth of older plants was obtained at 37° C (Table 1). Further studies showed that warm ambient air temperatures overcame the differential effects of cold root temperatures on growth of F. dumosa (Figure 5). It tends to be a hot-desert species and appears to be poorly adapted to cool and freezing temperatures. Zinc and copper contents of the plants grown in pots of soil at various temperatures were high compared to field-grown plants (compare with Table 3).

F. dumosa appears to be relatively insensitive to soil pH and to the presence of $CaCO_3$ (Table 2). Mineral composition indicated high boron contents. Copper, manganese, and zinc levels were increased with decreasing soil pH. Potassium and calcium contents were relatively high. The species appears to have a requirement for a high level of calcium (Figure 6).

Mineral composition of leaves of field-grown F. dumosa plants are in Table 3. The analyses confirm relatively high calcium and boron contents. Potassium was high and sodium was low. Copper contents for the high pH, calcareous soils of the Nevada Test Site were much lower than plants in Yolo loam, even with $CaCO_3$ added to the soil (Table 2). Field grown F. dumosa concen-

Table 2. Shoot yields and mineral composition on the dry weight basis of leaves of F. dumosa grown in Yolo loam soil with and without excess $CaCO_3$ or sulfur.

Measurement	$CaCO_3$ (pH 7.5)	Control (pH 6.0)	Sulfur (pH 4.2)
Leaf wt, g/plant	6.05	6.90	9.94
Stem wt, g/plant	10.05	11.79	12.39
Ca, %	2.42	2.12	1.73
K, %	3.26	3.56	3.21
Mg, %	.58	.58	.71
Na, %	.14	.17	.22
P, %	.29	.37	.66
B, ppm	233	213	207
Cu, ppm	29	42	57
Fe, ppm	162	165	171
Mn, ppm	118	167	688
Co, ppm	T	T	14.3
Mo, ppm	11.4	5.4	4.6
Zn, ppm	11	35	69

Means of determinations from 3 plants.

Figure 4. Growth response of F. dumosa cuttings to different soil temperatures. Note the succulent juvenile leaf form.

trates relatively high levels of aluminum in leaf tissue. Results also suggest that F. dumosa may be a boron accumulator.

F. dumosa seedling plants were grown 90 days in various soils (Figure 7). Best growth was in a soil with moderate pH and no salinity (Yolo) and in one with a fair amount of salinity (Panoche). Moderate growth occurred in calcareous Hacienda and Nye Canyon soil; low pH and low phosphorus Aiken soil resulted in little or no growth. These results may reflect somewhat the available nitrogen status of these soils inasmuch as F. dumosa responded to additions of nitrogen to the calcareous soil of the Mercury Valley study area.

F. dumosa is more resistant to ionizing radiation than are some other species and more sensitive than others (Figure 8). A lethal dose of acute gamma radiation for succulently growing specimens of this species was 4 kR. As is the case with several other shrub species, higher dosage levels are required to kill the shrub if irradiated while in the dormant state.

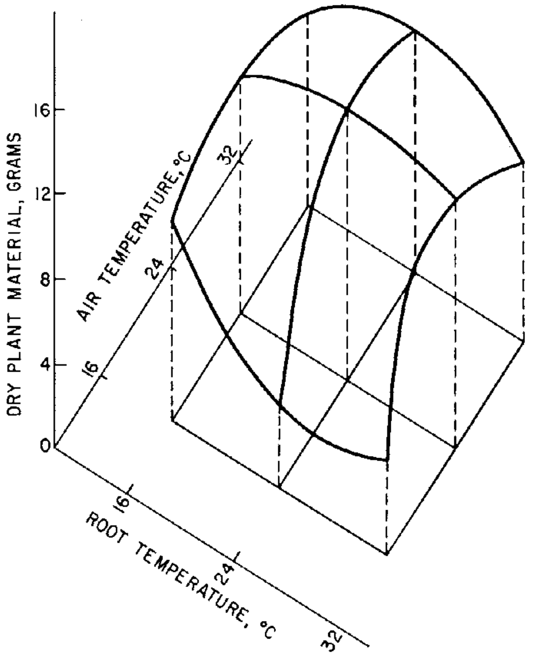


Figure 5. Growth response of F. dumosa to different combinations of air and soil temperatures.

Figure 6. Response of F. dumosa to varied calcium levels (10^{-4}N and 10^{-2}N) in solution culture.

Figure 7. Cuttings of F. dumosa grown 90 days in different soils.

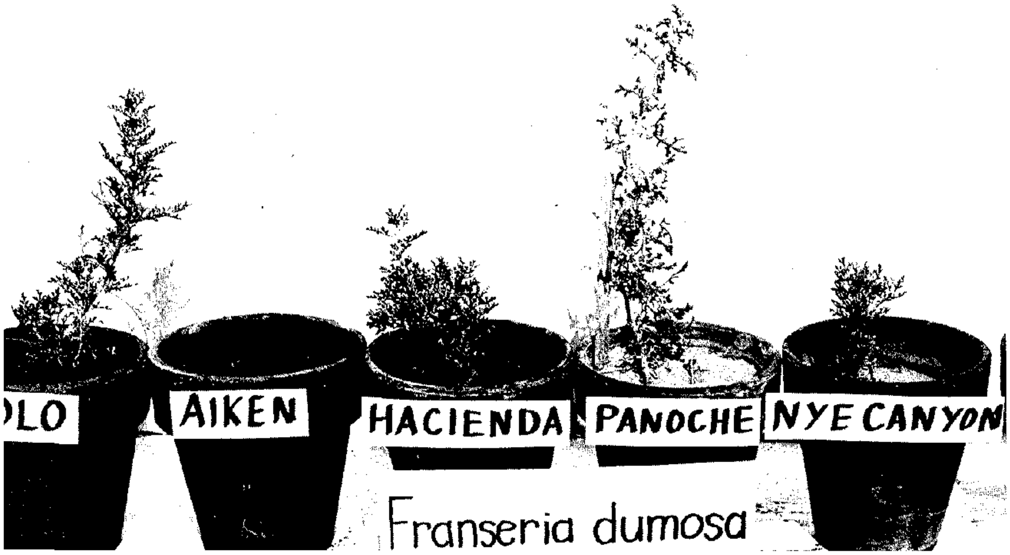


Table 4. Seasonal mineral contents, 1969 – *Franseria dumosa* (dry weight basis) samples collected from field.

Sampling date	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Co	Ni	Mo	Sr	Ba
	% of dry weight						ppm of dry weight											
							Leaf tissue											
4 Apr	.36	.071	2.30	2.26	.45	.29	51	15	658	45	84	739	26	0.9	3.0	2.6	44	14
21 May	.25	.058	4.42	1.53	.51	.12	36	5	155	15	124	172	7	T	1.0	4.5	37	12
19 June	.16	.073	3.89	2.83	.74	.36	33	5	235	26	212	648	31	T	1.1	5.4	64	9
29 July	.13	.046	2.84	3.18	.63	.26	38	11	293	27	275	378	20	1.2	0.9	5.5	67	8
24 Sept	.17	.061	2.21	3.85	.67	.33	72	58	439	35	339	669	29	1.5	1.3	4.3	80	12
							Stem tissue											
11 Feb	.09	.019	2.34	1.27	.31	.06	31	23	198	15	26	219	9	T	T	4.2	42	11
17 Mar	.13	.024	3.17	2.14	.45	.21	30	7	418	21	37	529	41	T	0.9	3.9	54	17
4 Apr	.06	.062	3.65	1.57	.61	.19	30	9	473	22	38	573	27	T	1.3	5.5	46	21
21 May	.11	.102	4.51	1.35	.64	.02	27	4	56	21	48	168	2	1.3	2.7	3.1	51	14
19 June	.08	.071	4.26	2.45	.71	.06	42	4	116	36	68	178	6	1.1	1.7	2.8	68	16
29 July	.07	.047	2.78	1.23	.43	.02	32	18	56	21	31	163	10	T	T	3.6	44	9
24 Sept	.06	.057	2.49	1.59	.44	.15	41	22	392	27	42	425	11	T	T	2.7	50	14
31 Dec	.09	.022	2.27	1.66	.41	.10	33	30	182	17	117	197	4	T	1.0	2.9	51	14

Mineral composition of *F. dumosa* leaves and stems on a seasonal basis is given in Table 4. The aging process is indicated for several of the elements. These processes can result in decreases of elements due to dilution by adding of carbohydrate-like materials or to dilution because of retranslocation either to other growing centers (could be roots as well as shoots) or to storage tissues (stems) prior to leaf abscission. Decreases in phosphorus in leaves with age was notable but there was slight indication only of build up in stems with age. The potassium contents of leaves increased, then decreased. There was little evidence of its storage in stems. Calcium, magnesium, silicon, zinc, copper, and boron in leaves tended to increase with age in leaves and this is another aging process related to translocation.

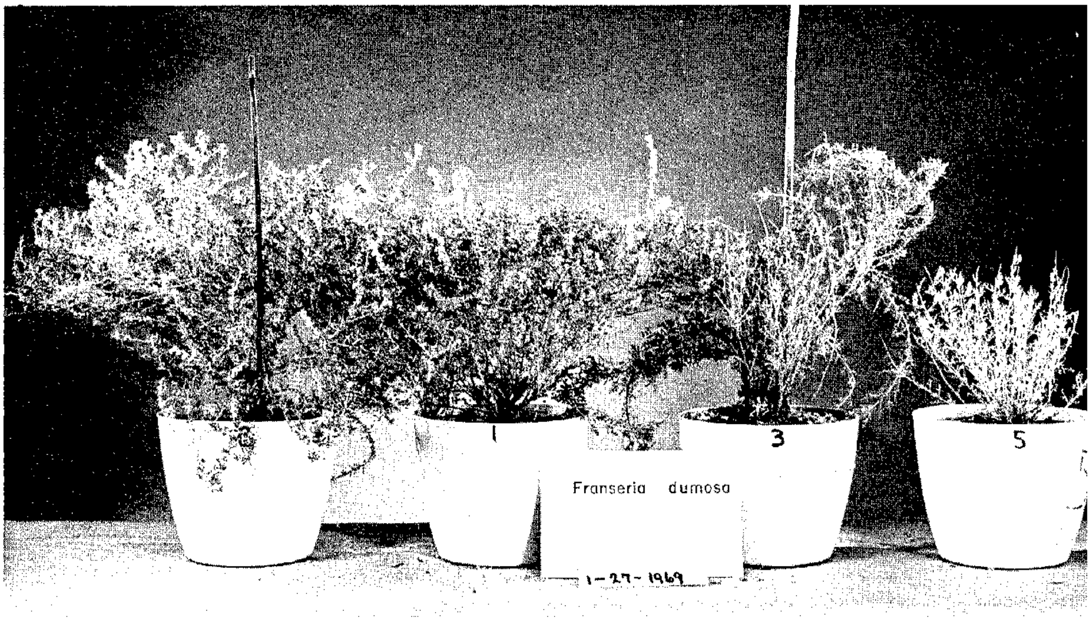


Figure 8. Acute gamma irradiation with 4 kR was lethal to *F. dumosa*. (left to right, 0, 1, 3 kR)

Summary

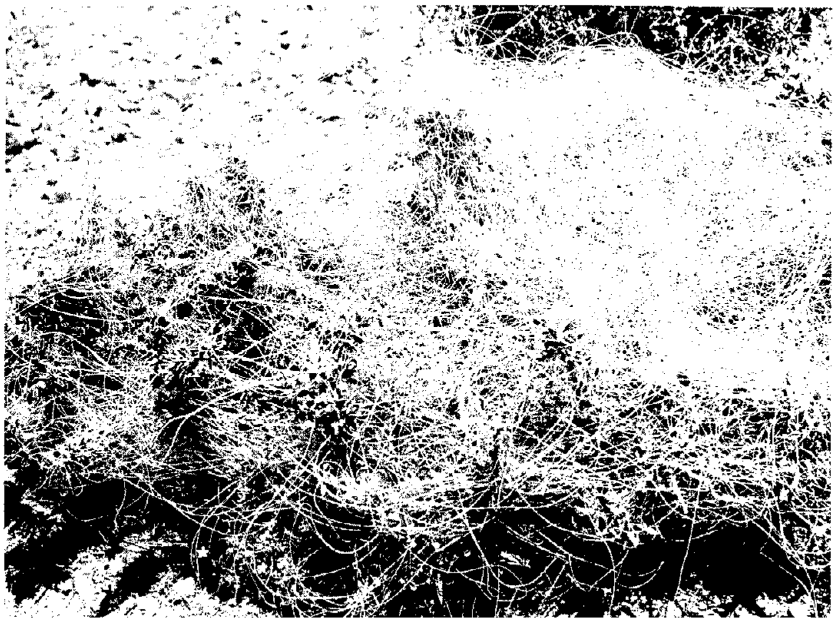
Franseria dumosa is a shrub which dominates or associates with *Larrea divaricata* at the Nevada Test Site. It is relatively short lived, compared with other shrubs. It is deciduous depending more upon soil moisture than on hot or cold temperatures. Late summer rains of sufficient magnitude cause it to resume growth, flower, and set seed, thus sometimes completing two productivity cycles in a given year. It sets fruits in any season of the year. Leaf drop under conditions of stress may be a survival mechanism under desert conditions. Root growth of seedlings is extremely rapid. *F. dumosa* requires warm conditions for growth, especially warm soil and air temperature, and it is not found at high altitudes. Low soil temperature (11°C) greatly decreased growth. Freezing injured the vegetative growth. It is tolerant of a moderate degree of salinity and is relatively insensitive to soil pH. It accumulates large quantities of boron and of calcium. It is moderately resistant to ionizing radiation.

CHARACTERISTICS OF CUSCUTA NEVADENSIS (DODDER)

Dodder (Cuscuta nevadensis, Johnston) is an interesting ecological factor at the Nevada Test Site and in adjacent areas. This plant is a nonchlorophyll-containing parasite which infests many other plant species. Its activity varies from year to year, but it seems to be especially active during growing seasons following winter and spring months which receive above-average rainfall. The growing season of 1969 was an exceptionally active period for dodder at the Nevada Test Site. It was seen to infest the following plant species in a manner as shown in Figures 1 and 2: Franseria dumosa, Larrea divaricata, Atriplex confertifolia, Atriplex canescens, Acamptopappus shockleyi, Lycium andersonii, Lycium pallidum, Hymenoclea salsola, Mirabilis pudica, Grayia spinosa, Dalea fremontii, Kameria parvifolia, Coleogyne ramosissima, Encelia virginensis, Eurotia lanata, and Prosopis juliflora, var. torreyana.

Large areas were seen in which most shrub species present were infested. One striking example occurred in an area which measured 1.0 km long x 0.5 km wide near an old abandoned highway on the West Frenchman Flat bajada. Another area about three times as large was seen alongside the Charles Brown Highway midway between Shoshone, California and Pahrump, Nevada. A site covering about one hectare was found in Rock Valley near the permanent gamma radiation source area. Visits to these areas during the spring of 1970, following very dry winter and spring months, showed an arrested activity of the dodder infestation. It was still present but there was no rank growth as in the previous growing season. Also, there was considerable evidence of severely damaged and/or dead shrubs of the species which had been severely infested in 1969. There appeared to have been no correlation of age of shrubs (size range) with dodder infestation. Both old and young shrubs were similarly in-

Figure 1. Lycium pallidum shrub infested with dodder, Cuscuta nevadensis)



fested and killed or damaged. New crown-sprouting was observed on *L. pallidum* and *L. divaricata* that had been severely damaged. The mineral composition of dodder (Table 1) appeared to be much like that for plants on which it grows.

Table 1. Mineral composition of *Cuscuta nevadensis*.

Location	P	Na	K	Ca	Mg	Si
			% of dry weight			
Frenchman Flat	0.33	0.25	5.76	0.42	0.22	0.11
Rock Valley	0.30	0.08	4.89	0.54	0.21	0.18

Location	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
					ppm of dry weight							
Frenchman Flat	19	4	194	21	24	243	13	2.0	0.5	1.2	13	8
Rock Valley	8	3	278	28	30	374	24	0.5	0.5	0.5	13	9

Summary

Dodder (*Cuscuta nevadensis*) is an important ecological factor because of its parasitic nature. It infests many shrub species and may kill or severely damage them. Dodder, like fires and prolonged droughts, could initiate a succession cycle and perhaps change a shrub climax to a grassland as often happens when water balance is changed in an area either by supplementary irrigation or by removal of existing shrubs.

Figure 2. *Larrea divaricata* infested with *Cuscuta nevadensis*.

CHARACTERISTICS OF KRAMERIA PARVIFOLIA

Krameria parvifolia Benth. is a low-growing shrub commonly appearing in the Mojave-like portions of the Nevada Test Site. It is commonly associated with Larrea divaricata and other shrub types as a dominant or associated species (Beatley, 1965, 1969). It appears as a single shrub or in a shrub clump with other species.

Shreve and Wiggins (1964) describe the species as follows:

> Krameria parvifolia Benth., Bot. Sulph. 6, pl. 1, 1844, var. parvifolia.
>
> Intricately branched shrub 3 - 6 dm high, somewhat depressed, with stout, gray-barked branches and slender, short-strigose twigs; leaves linear, sessile, acute, 1 mm wide or less, 8 - 12 mm long, short-strigose, green; peduncles 1 - 2 cm long; bracts linear, 4 - 6 mm long; sepals narrowly oblong, obtusish, 7 - 10 mm long, reddish at base, sparingly strigose; lower petals nearly rectangular, 3 mm long, smooth, truncate; upper petals united only at base, 4 - 5 mm long, blade of middle one narrowly oblong, those of lateral ones expanded; stamens borne on short claws of upper petals, about equaling petals; fruit somewhat compressed, subcordate, 7 - 8 mm broad, 5 - 7 mm thick, apex acute, sparsely strigose; spines acicular, 2.5 - 3.5 mm long, glabrous, bearing 2 - 4 retrorse barbs at two or three levels near apex. Dry washes and rocky hillsides, southern Baja California from the vicinity of Magdelena Bay southward. March - Sept.

Benson and Darrow (1954) state that K. parvifolia is found on rocky slopes and gravelly plains in the desert at 160 to 1600 meters elevation. It inhabits deserts in California from the Death Valley region and Victorville southward and eastward; southern Nevada; southwestern Utah; Arizona in the Grand Canyon region, in the Mojave, Colorado, and Arizona deserts, and in the desert grassland. This species is an important browse plant for range livestock, and the significance is increased by the fact that the associated vegetation often includes few other palatable plants. The shrubs are resistant to grazing, and they sprout readily from their shallow root systems. After a few years each plant becomes a dense, rounded, spiny mass from which the new year's tender growth protrudes. The plant is also reported to be a root parasite.

K. parvifolia is fairly abundant in Mercury and Rock Valleys. Its relative frequency in two plots in Rock Valley were 22 and 4.4% with a total of 5586 and 4272 shrubs of all species per hectare.

K. parvifolia is a most interesting shrub. At the Nevada Test Site, it remains dormant in the spring for at least a month longer than most other shrubs and then it holds its leaves for at least two months longer than most other deciduous species in the summer. Its temperature and day-length requirements would be unique (see page 387). Its rambling growth habit (Figure 1) results in large numbers of winter annuals growing in association with it. Contributing to this phenomenon is the ability of this species to spread by underground stolons (Figure 2). This habit with several shoots close together helps to provide the catchment which collects fallen leaves and wind-blown soil particles making a more suitable environment for annual plant species.

We observed K. parvifolia to continue active growth even after the soil moisture level had dropped below 3 per cent and other nearby deciduous shrubs

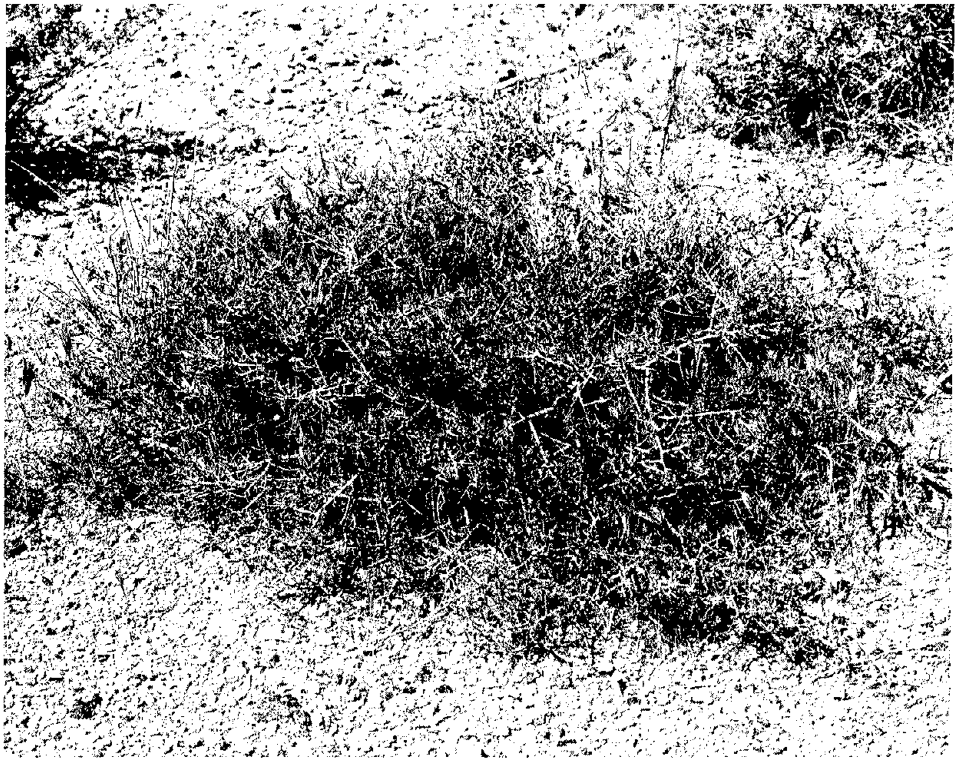


Figure 1. K. parvifolia showing its rambling growth habit and annual plant species growing in association with it.

Figure 2. Underground stolon and shoot production on K. parvifolia.

Table 1. Seasonal mineral contents of *K. parvifolia* sampled at intervals during 1969 at Mercury, Nevada.

Sampling date	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Co	Ni	Mo	Sr	Ba
	% of dry weight						ppm of dry weight											
Leaf tissue																		
21 May	.24	.059	1.96	1.41	.42	.06	32	10	117	37	51	137	7	T	1.7	2.7	34	9
19 June	.10	.075	2.02	1.12	.51	.10	20	9	222	32	49	185	4	T	T	2.8	42	11
29 July	.17	.101	2.11	1.42	.60	.14	14	10	385	51	86	287	9	T	T	1.7	50	13
24 September	.16	.081	1.25	1.82	.55	.51	22	4	934	56	62	994	74	T	T	2.9	51	18
Stem tissue																		
11 February	.03	.015	.08	.82	.16	.37	27	39	1104	27	19	775	47	1.4	3.4	2.9	28	11
17 March	.03	.013	.16	.82	.13	.31	15	17	985	24	18	649	40	0.8	1.3	2.3	27	9
4 April	.06	.024	.35	.67	.19	.27	25	26	846	28	20	660	19	0.9	3.2	2.3	24	14
21 May	.13	.023	1.24	1.09	.24	.04	13	8	240	10	18	177	3	T	T	T	35	12
19 June	.09	.024	.89	.67	.26	.13	15	8	267	14	43	287	18	T	T	2.4	33	11
29 July	.07	.010	.52	.67	.20	.07	13	14	256	12	19	197	8	T	T	1.8	30	9
24 September	.04	.014	.19	.99	.22	.25	27	29	879	22	24	632	42	1.0	2.4	2.1	33	11
31 December	.09	.018	.54	.94	.19	.15	23	22	768	20	27	675	48	1.3	2.7	1.3	81	17

had shed their leaves and gone dormant. This amazing capacity to continue growth in virtually dry soil suggests that K. parvifolia may obtain moisture directly from the atmosphere through foliage. Its rambling growth habit close to the ground and its role as an understory shrub when associated with other species should enhance its capacity to benefit from dew formation. K. parvifolia is reported to form root grafts with other species which subsequently should permit it to obtain moisture from other root systems; however, we have found no evidence of root grafts in our excavations of several shrub root systems at the Nevada Test Site.

Experimental Results

All attempts of root cuttings of K. parvifolia so far have failed and only two seeds have been collected which germinated. Most seeds produced in the field appear to have been injured by insects. In fact, insects may be an important regulatory mechanism for reseeding of this species. Attempts have been made to transplant specimens from the field into pots, but these likewise have failed except for a few cases.

Mineral composition of K. parvifolia sampled at different intervals in 1969 from the field is given in Table 1. Note the interesting build-up of sodium and potassium during the period of most active new photosynthetic productivity in both leaf and stem tissues, and the high levels of iron and aluminum accumulated by this species. Of particular significance is the decrease of zinc, copper, iron, manganese, aluminum, and titanium in stem tissues during the peak productivity period (May, June, July) indicative partly of having been stored in stem tissues and translocated to the new crop of leaves.

Summary

Krameria parvifolia is a low-growing shrub species usually associated with Larrea. It is sometimes dominant and many annual plants grow in association with it. Its growth habit results in its being associated with large numbers of winter annuals. It spreads by growth of underground shoots (stolons) and forms root grafts with other species. It is dormant for a month longer than most species in the spring, and remains active for about two months longer than other deciduous shrub species. Presumably it has a high temperature requirement. Insects appear to regulate its reseeding. Attempts to obtain rooted cuttings and seedlings have not been successful. This shrub accumulates relatively high levels of aluminum and iron, and low levels of sodium. It continues active growth even when the soil moisture level drops below 3 per cent.

CHARACTERISTICS OF ATRIPLEX SPECIES (SALT BUSHES)

Atriplex species are widely distributed over the western United States as well as in other parts of the world and in general are related to dry alkaline and saline soils.

Shreve and Wiggins (1964) give the following description of some of the Atriplex species:

> Atriplex canescens (Pursh) Nutt., Gen. Pl. 1:197, 1818, subsp. canescens. Erect shrub to 2.5 m high with stout, terete branches, these gray-scurfy in youth, soon glabrate and pale; leaves subsessile or sessile, linear-spatulate to oblong, 2 - 8 mm wide, 1.5 - 5 cm long, entire, densely gray-scurfy; flowers dioecious, staminate in dense, nearly leafless terminal spikes and panicles, pistillate in dense, leafy-bracted spikes and panicles; fruiting bracts 6 - 15 (sometimes 20) mm long, with wings 4 - 8 mm wide, shallowly to deeply toothed, similar wings usually along median line of outer face, smooth or slightly appendaged between wings; seeds 1.5 - 2 mm long.
>
> Dry alkaline soils, South Dakota to Kansas, western Texas, eastern Washington, and south into Baja California, Sinaloa, and Zacatecas. March - Sept.
>
> Atriplex hymenelytra (Torr.) S. Wats., Proc. Amer. Acad. 9:119, 1874. Compact, profusely branched shrub 2 - 12 dm high with dense, persistent, white scurf on young twigs and leaves; branches somewhat tortuous, stoutish, erect or ascending; bark tan on younger wood, finally gray and more or less checked and fissured; petioles 3 - 10 mm long; leaf blades round-ovate to orbicular, 1.5 - 4.5 cm wide and long, truncate to subcordate at base, obtuse at apex, saliently and irregularly toothed, silvery with a dense, smooth scurf, turning red to purplish with age; flowers dioecious, in dense, leafy panicles; bracts borne on a turbinate stalk 2 - 4 mm long, orbicular, 6 - 10 mm long, strongly compressed, distinct except at base, margins entire, faces smooth or reticulately veined on body of the fruit; seeds 1.5 - 2 mm long.
>
> Alkaline flats and slopes, Lower Sonoran Zone, southwestern Utah, southern Nevada, and southeastern California from Inyo County south through the Mojave and Colorado Deserts to central Baja California, western Arizona, and northwestern Sonora. Feb. - April.
>
> Atriplex lentiformis (Torr.) S. Wats., Proc. Amer. Acad. 9:118, 1874. Erect shrub 1 - 3 m high with flexuous or rigid or angular branches forming a dome-shaped outline, the lateral twigs sometimes spine-tipped; leaves deltoid, rhombic, ovate, or oblong, 0.5 - 2.5 cm wide, 1 - 5 cm long, truncate to broadly cuneate at base, obtuse and often short-mucronate at apex, entire to subhastate, closely and finely gray- or blue-scurfy; flowers dioecious or sometimes monoecious, in crowded clusters along branches of diffuse panicles 1 - 5 dm long; bracts orbicular or slightly broader, compressed-lenticular, 2.5 - 5 mm broad, margins entire to crenulate, faces smooth, gray-scurfy; seeds 1.2 - 1.5 mm long, dark brown.
>
> Alkaline flats and benches, desert outwash slopes and playas, and interior valleys, Lower Sonoran Zone, Salinas and San Joaquin Valleys,

California, to southwestern Utah, south through the Mojave and Colorado Deserts to central Baja California, and east to central Arizona and northwestern Sonora. Feb. - April.

Munz (1959) gives the following description of Atriplex confertifolia:

> A. confertifolia (Torr. & Frém.) Wats. [Obione c. Torr. & Frém.] Erect rigidly branched spiny rounded shrub 2 - 10 dm high, with stout scurfy branchlets; lvs. crowded, deciduous, alternate, round-ovate or -obovate to elliptic, obtuse, subsessile or short-petioled, 1 - 2 cm long, entire, gray-scurfy; plants dioecious, the male glomerules in the upper axils, almost spicate, the female 1-few in each of upper lf.-axils; fruiting bracts sessile, convex over the seed, suborbicular, free-margined, entire, 6 - 12 mm long; seed red-brown, 1.5 - 2 mm in diam.—Common, alkaline flats and slopes, below 7000 ft.; Shadscale Scrub, Sagebrush Scrub, Creosote Bush Scrub; Mojave Desert to e. Ore., N. Dak., Chihuahua. April - July.

Benson and Darrow (1954) give the following description of A. polycarpa:

> A. polycarpa (Torr.) S. Wats. CATTLE SPINACH (1) Bracts with fingerlike projections on the margins; (2) leaves small, only about 1/4 inch long, without petioles (stalks), often in dense clusters (fascicles). Shrubs usually about 1 m high, rounded; branches smooth, the bark soon splitting; leaves oblong but the apices acute or nearly so, about 5 - 7 mm long, usually 1.5 - 3 mm broad, rather thick, markedly scurfy; bracts of the fruits, or most of them, with irregular projections or crests from especially near the bases of the backs, these resembling the fingerlike lobes on the margins, silvery-scurfy with very dense scales.—Alkaline plains and occasionally rocky or gravelly slopes in the desert or in grassland at 400 to 3000 ft. elevation. California in scattered localities in the San Joaquin Valley and in the Mojave and Colorado deserts; southern Nevada, southwestern Utah, Arizona in Bill Williams River drainage and in the Colorado and Arizona deserts; Baja California and southeastward in Mexico.

Beatley (1965, 1969) reports that at the Nevada Test Site A. canescens is occasional to common and usually in sandy soils. It is associated with all vegetation types except Pinyon-Juniper and is present in all basins of the Nevada Test Site. It is the dominant shrub in some local areas.

A. canescens is dioecious (Figure 1). It grows rapidly, mostly on sandy soil and along disturbed roadsides where there is extra water. There is a heavy cover of it at Cane Springs where water is available. It is believed by some to be a phreatophyte. It has been the only shrub to become reestablished near ground zero of the Sedan nuclear cratering test of 1962.

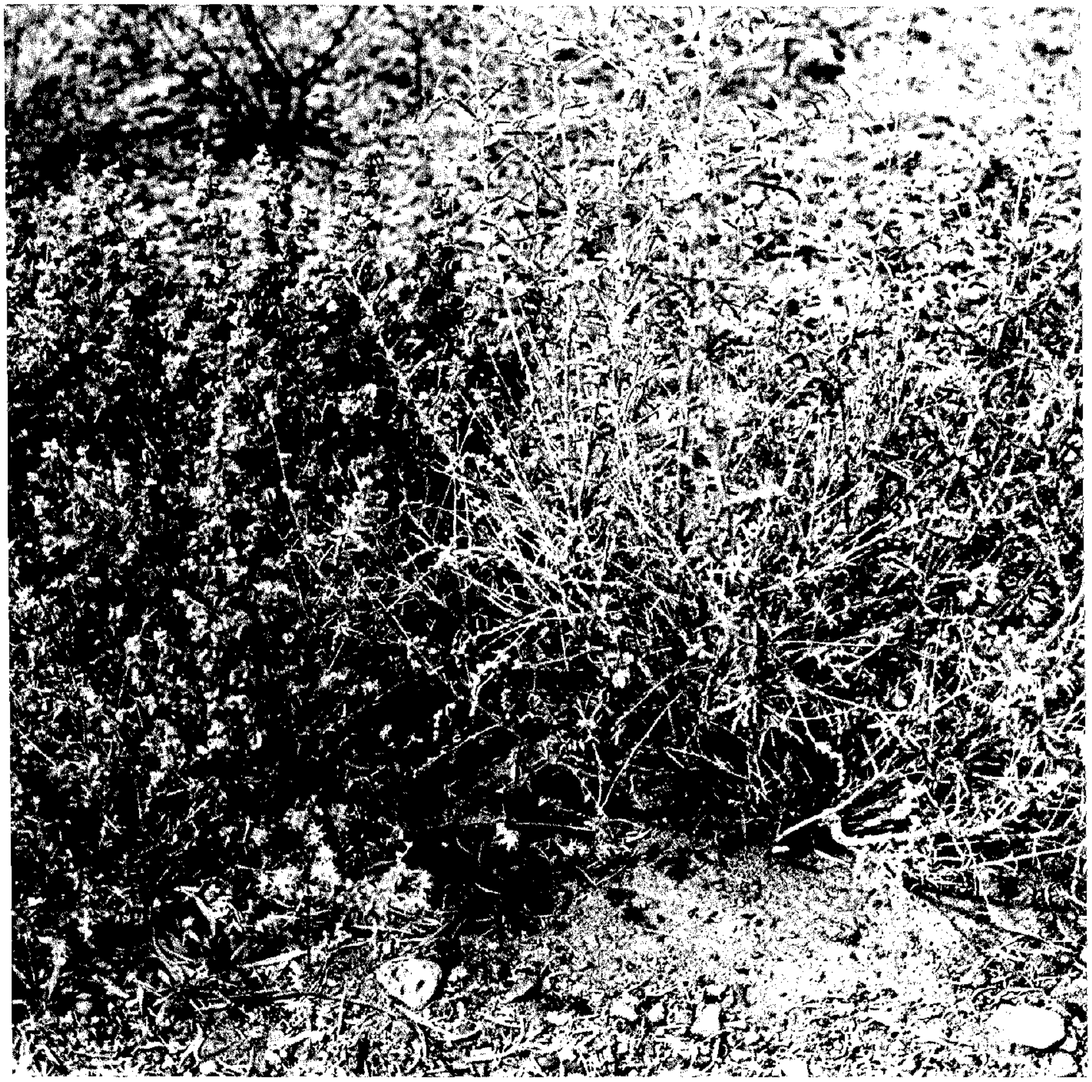
A. confertifolia is widely distributed and occurs as a dominant shrub or even as a nearly pure stand, especially near the Frenchman and Yucca playas and on the bajadas and hills of the south Frenchman and southwestern Yucca Flat (Beatley, 1965, 1969).

A. confertifolia associations at the Nevada Test Site include Atriplex-Kochia and Atriplex-Eurotia north of Yucca playa, and essentially pure stands of Atriplex north of Frenchman playa. Certain sandy sites are occupied by A. canescens communities. A. confertifolia is also a dominant with Larrea or Coleogyne on slopes of calcareous hills, as on the bajadas and in the foothills of northern Mercury, southern Frenchman and southwestern Yucca Flat (Beatley, 1965, 1969).

A. confertifolia is one of the higher plant species of the Great Basin, Mojave, and Sonoran Deserts that grows in saline and semisaline areas (Billings, 1949; Branson et al., 1967; Gates et al., 1956; Shantz, 1940).

A. confertifolia is dioecious (Figure 2) and has a very high osmotic pressure in leaves. It has leaf salt glands as do Atriplex species in general. In the field its leaves are often cool to the touch and sometimes appear wet.

Figure 1. A. canescens, pistillate and staminate shrub forms.



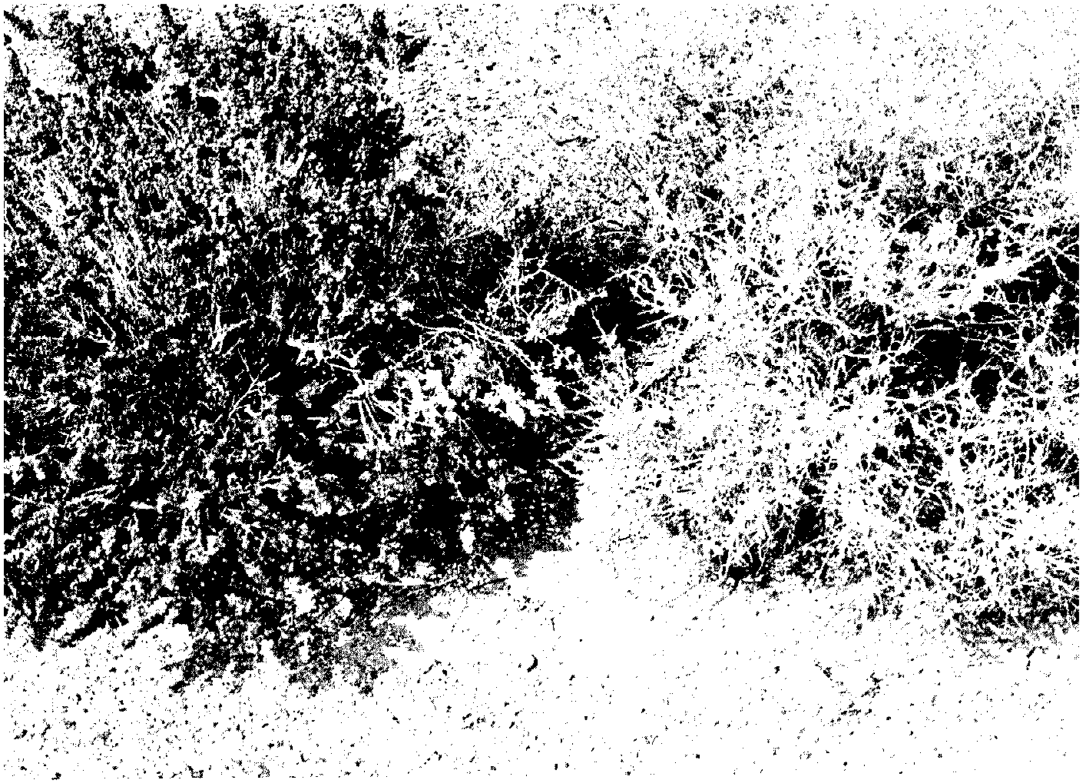
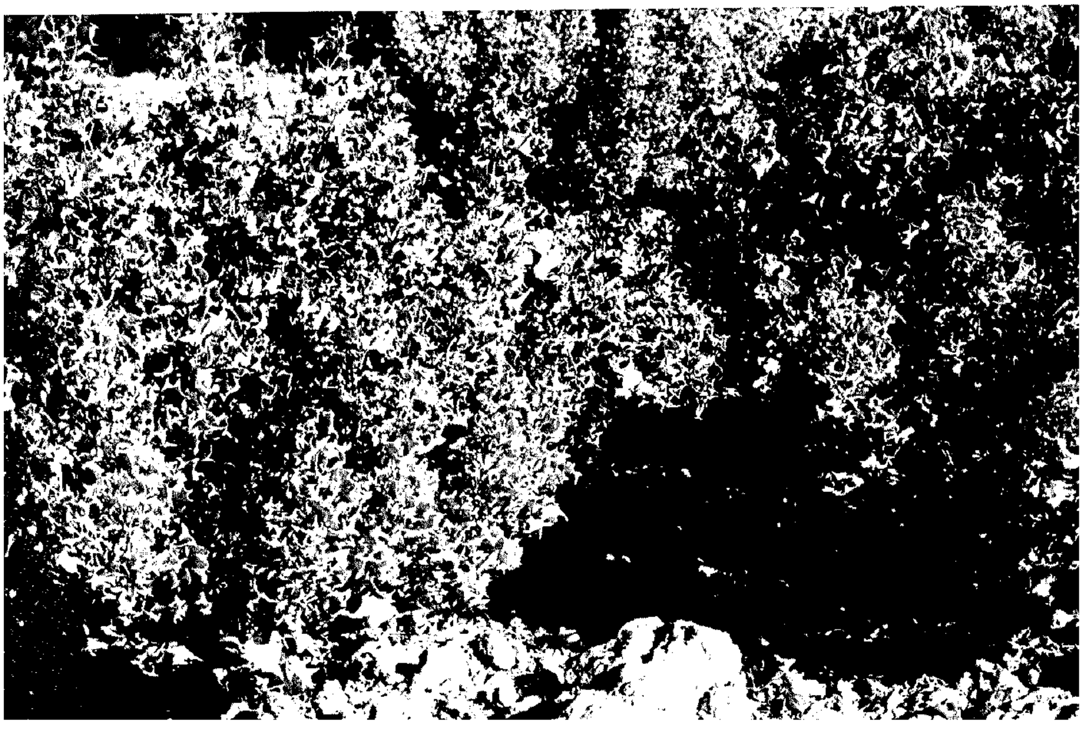


Figure 2. A. confertifolia, pistillate and staminate plants.

Figure 3. A. hymenelytra, commonly called desert holly.

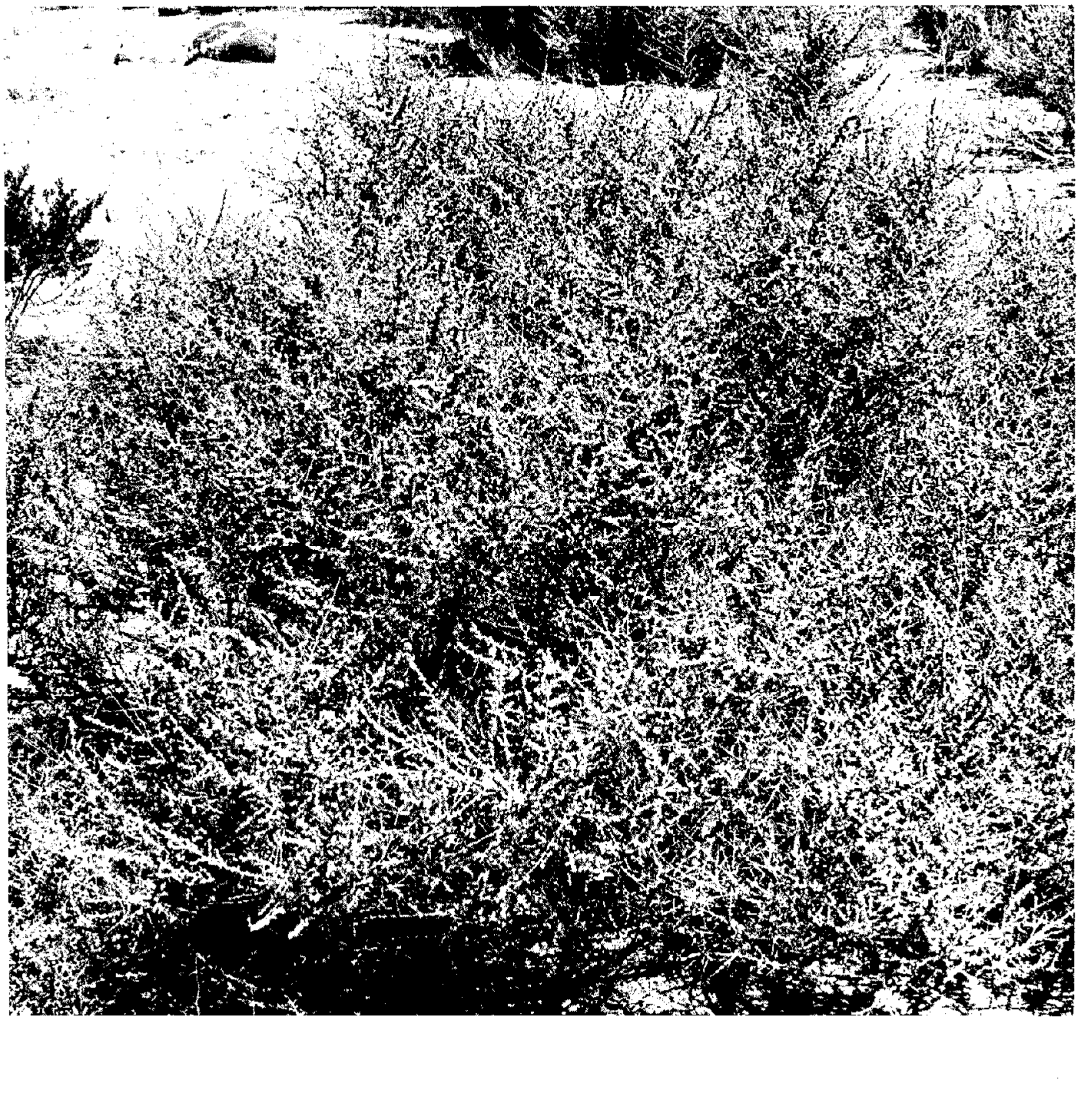


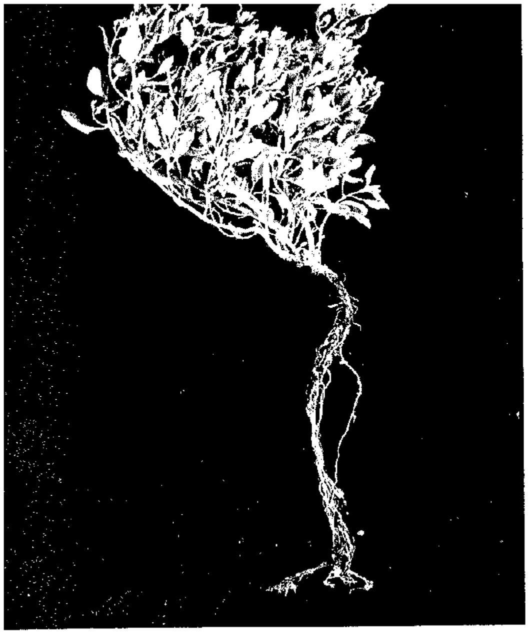
In September of 1967,3 new specimens of A. canescens were observed on disturbed soil at 2100 m elevation. A. confertifolia generally occurs at lower elevations.

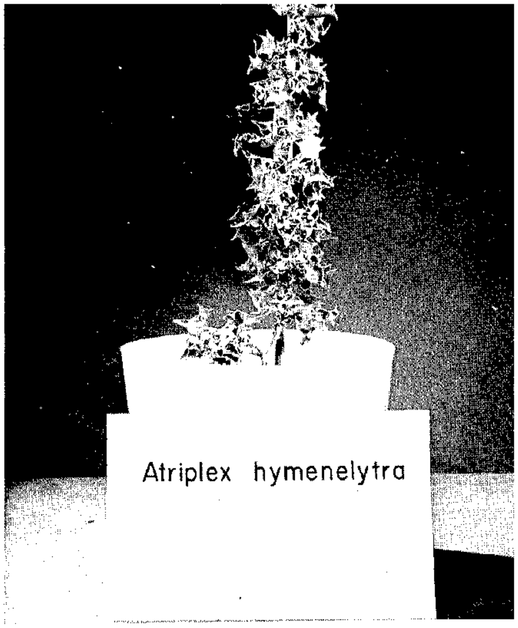
A. hymenelytra (Figure 3) occurs occasionally along disturbed sites or in washes of west Mercury Valley, south Jackass and north Frenchman Flats. It commonly grows in Death Valley. Both it and some other Atriplex tend to be distributed in areas more like the Mojave Desert than like the Great Basin Desert.

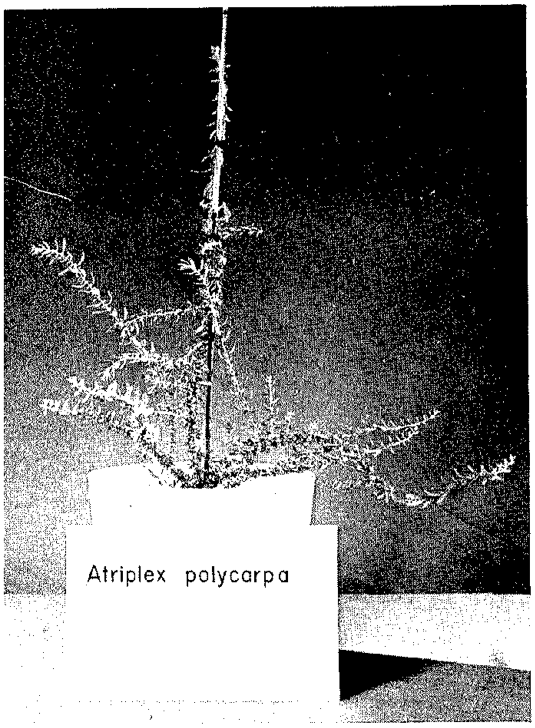
A. polycarpa (Figure 4) and A. rosea L. also are found in washes and

Figure 4. A. polycarpa, commonly called cattle spinach.









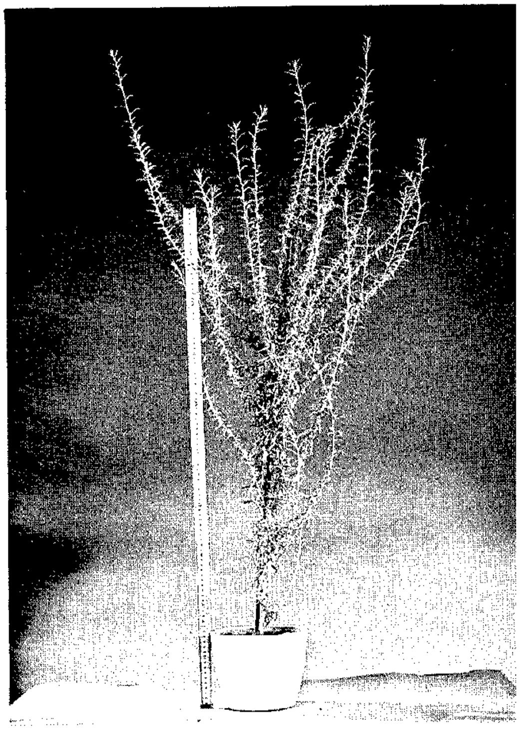


Figure 5. (top left) Rooted cutting of A. confertifolia.
Figure 6. (top right) Potted cutting of A. hymenelytra.
Figure 7. (bottom left) Potted cutting of A. polycarpa.
Figure 8. (bottom right) Potted cutting of A. canescens.

hills of south Frenchman Flat (Beatley, 1965).

In one section of Frenchman Flat the *Larrea*-*Atriplex* transition line contains many dead *A. canescens*. New *A. canescens* were growing at the same sites where the old skeletons remain, the sites being favorable spots for seedlings to germinate and survive. The evidence indicates that the old plants had died of drought and that the *L. divaricata* had survived the drought. Dating by annual rings indicates that the new *A. canescens* plants are about 20 years old.

Osmond and colleague (1963, 1968a, 1968b, 1968c) have studied some of the physiology of *Atriplex* in Australia. They found high levels of oxalate in leaves in association with cations. They found that oxalate was absorbed by cells with characteristics which indicated absorption through the tonoplast into the vacuole. They found that sodium uptake was largely exchanged with potassium. Divalent cations were low in tissues because of large quantities of sodium and potassium in them. Photosynthesis in the *Atriplex* studied seemed to have an initial C-4-dicarboxylic acid pathway in contrast to the usual Calvin pathway. This contributes to their efficiency in growth (Hatch and Slack, 1970; Black et al, 1969).

Experimental Results

A. canescens, *A. lentiformis*, and *A. hymenelytra* seeds readily germinate under glasshouse conditions. Those of *A. confertifolia* do not; we have had only a few of the seeds germinate of the hundreds planted, but these have resulted in hundreds of cuttings. Cuttings of *Atriplex* usually root readily (Figure 5, 6, 7, 8) if the plants from which cuttings are taken are in a juvenile form (Figure 9). For successful rooting of cuttings, no growth regulator is used and the cuttings are placed either in an open glasshouse or in a box kept at about 15°C with bottom heat at about 25°C for rooting. *A. canescens* and *A. hymenlytra* cuttings root readily under the same procedures.

A. canescens seedlings gave yield response to sodium in solution culture, but did not in soil. Those in solution were grown for 30 days in 1800 ml of complete nutrient solution with varying levels of NaCl superimposed. Yields and sodium contents are shown in Table 1. There appeared to be a growth response for 5, 10, and 20 m*M* NaCl but 50 m*M* appeared to depress growth. Sodium appears to be slowly translocated to shoots of *A. canescens* in contrast to many plant species. The sodium content of these plants was much lower than that of *A. confertifolia* as is well known.

Table 1. Effects of NaCl on yields and sodium contents of plant parts of *A. canescens* grown in solution culture.

Treatment	g dry wt of 4 plants				Sodium content (% dry wt)		
m*M* NaCl	Root	Stem	Leaf	Whole plant	Root	Stem	Leaf
0	0.45	0.95	2.48	3.88	0.15	0.08	0.16
1	0.37	0.90	2.25	3.52	0.21	0.07	0.14
5	0.35	1.00	3.06	4.41	0.67	0.11	0.26
10	0.46	1.15	2.74	4.35	0.47	0.14	0.57
20	0.48	1.25	3.65	5.38	0.50	0.18	0.86
50	0.45	0.83	1.93	3.21	0.48	0.41	1.53

A. canescens behave a little differently in soil. Seeds were planted January 26, 1967 in fine vermiculite and seedlings emerged about one week later. Seedlings were transplanted to a regular potting soil (Yolo loam, pH 5.7) with some sand and coarse vermiculite, and placed in the glasshouse. Plants grew well and by April 17, 1967 were husky and compact, 15 cm high. On this date NaCl was added at treatment levels of 0, 0.7, 1.4, 2.1, 2.8, and 3.5 g per pot. On May 4, 1967 the same increments were again added. The total NaCl application was equivalent to 0, 4, 8, 12, 16, and 20 tons per acre. The plants were harvested on May 17, 1967. Since the time of the first NaCl application they had tripled in size. Yield and mineral contents are given in Table 2.

A. canescens was slightly sensitive to acid soil when it was grown in soil acidified with 2% sulfur (Table 3). It was relatively insensitive to added $CaCO_3$. Micronutrient contents were greatly related to the soil pH, especially manganese, zinc, and molybdenum. Growth was considerably different when seedlings were grown for 5 months in acid, neutral, saline, and calcareous soils

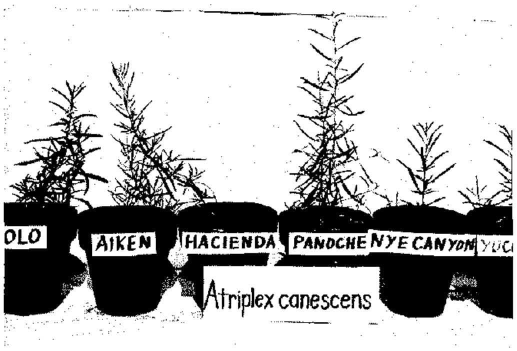
Table 2. Yield and chemical analyses of shoots of *A. canescens* grown in soil on a per pot basis.

NaCl treatment (g/pot)*	Net dry wt of 2 plants, g	Mineral content (% dry wt)				
		P	K	Na	Ca	Mg
0	6.66	0.48	4.74	0.10	1.49	0.76
0.7	6.93	0.62	5.11	1.24	2.26	0.85
1.4	6.44	0.51	5.12	2.29	2.34	0.83
2.1	6.88	0.42	4.91	1.73	1.38	0.69
2.8	6.12	0.42	4.82	3.78	2.13	0.77
3.5	6.03	0.44	4.31	5.86	2.35	0.70

*Equivalent to 0, 4, 8, 12, 16, and 20 tons NaCl per acre when added twice.

Table 3. Shoot yields and mineral composition on the dry weight basis of leaves of *A. canescens* grown in Yolo loam soil with and without excess $CaCO_3$ and sulfur. (Mean of 3 plants.)

Measurement	$CaCO_3$ (pH 7.5)	Control (pH 6.0)	Sulfur (pH 4.2)
Leaf wt, g/plant	13.07	15.05	11.23
Stem wt, g/plant	14.71	15.50	7.55
Ca, %	0.78	0.95	1.41
K, %	7.25	7.57	5.73
Mg, %	0.59	0.84	1.16
Na, %	0.18	0.14	0.22
P, %	0.31	0.80	1.31
B, ppm	62	52	58
Cu, ppm	21	45	69
Fe, ppm	52	49	73
Mn, ppm	80	267	680
Co, ppm	T	T	2.9
Mo, ppm	12.5	6.4	2.8
Zn, ppm	32	170	>200



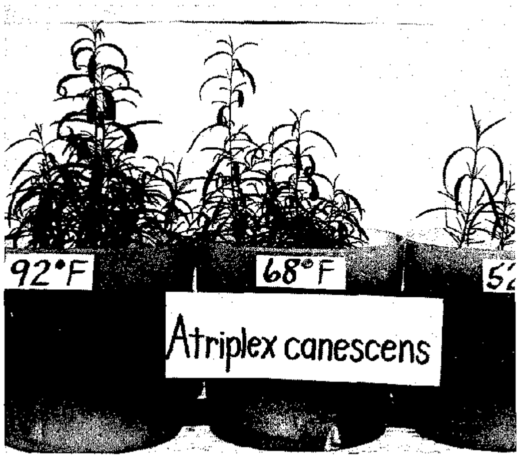


Figure 9. (top left) Juvenile forms of A. confertifolia suitable for rooted cuttings.

Figure 10. (top right) Growth of A. canescens on different soil types: Aiken is acidic; Yolo is neutral; Hacienda, Nye, and Yucca are calcareous; Panoche is calcareous-saline.

Figure 11. (bottom left) A. canescens response to nitrogen added to calcareous Mercury area soil. (0, 110, 330 kg per ha)

Figure 12. (bottom right) A. canescens grown at different soil temperatures and ambient glasshouse air temperatures.

(Figure 10). Poorest growth was on acidic Aiken soil and best growth was on calcareous-saline Panoche soil.

A. canescens responded to nitrogen treatments applied to calcareous soil from Mercury, Nevada at levels equivalent to 110 and 330 kg nitrogen per hectare (Figure 11).

A. canescens was one of the most responsive of the Atriplex species to changes in soil temperature (Figure 12). Yield was much greater at 33°C than at 11°C root temperature after a 75-day growth period.

The initial observations just discussed prompted a series of additional soil pot and solution culture experiments to further investigate some mineral nutritional characteristics of Atriplex species and their response to changes in root temperature.

A. canescens seedlings were grown in culture solutions in 3700 ml jars for 71 days. Composition of the nutrient solutions used is given in Table 4. Solutions were changed twice during the experiment. When harvested the test plants were separated into leaves, stems and roots. Each was washed with 0.1N HCl and then with water. Plant materials were dried, weighed, and ground for analysis by an emission spectrograph (methods of Alexander and Romney).

Table 4. Composition of nutrient solutions in which *A. confertifolia* cuttings and *A. canescens* seedlings were grown.

Solution variables*	KH_2PO_4	$Ca(NO_3)_2$	$MgSO_4$	K_2SO_4	Other
			me/liter		
Control	2.0	10.0	2.0	6	—
1/20 P	0.1	10.0	2.0	8	—
No Fe	2.0	10.0	2.0	6	—
1/20 K	0.0	10.0	2.0	0.4	2 $NH_4H_2PO_4$
1/10 N	2.0	1.0	2.0	6	9 $CaSO_4$
No Zn	2.0	10.0	2.0	6	—
1/10 Mg	2.0	10.0	0.2	6	—
Na	2.0	10.0	2.0	6	5 Na_2SO_4
1/10 N + Na	2.0	1.0	2.0	6	9 $CaSO_4$ 5 Na_2SO_4
NH_4NO_3	2.0	10.0	2.0	6	10 NH_4NO_3
Urea	2.0	10.0	2.0	6	10 urea
$NH_4^+ + CaCO_3$	2.0	—	2.0	6	10 $(NH_4)_2SO_4$ and $CaCO_3$

*Micronutrients except where omitted were added as mmoles/l: 0.01 FeEDDHA, 0.015 $ZnSO_4$, 0.09 $MnSO_4$, and 0.045 H_3BO_3, 0.003 H_2MoO_4.

Another experiment was made with *A. canescens* in solution culture. Plants were grown with 0, 10, and 90 me per liter of Na_2SO_4 superimposed upon the complete nutrient solution in 7 liters of the solution with weekly changes for 3 months. Plants were separated, dried, and analyzed for sodium by a flame photometer procedure.

The data for nutrient variables with *A. canescens* are in Table 5. This species appeared to respond to sodium with increased yields. Sodium contents, however, were relatively small as were those of potassium relative to that which occurred in *A. confertifolia* as will be shown later. The gradient of sodium and potassium from leaves to stems to roots was poorly pronounced in *A. canescens*. Zinc and copper contents were also lower.

The results for *A. canescens* plants grown at 0, 10, 90 me per liter of Na_2SO_4 are in Table 6. There were no particular detrimental effects of the high sodium and the quantities in plants were not great. The sodium appeared to accumulate in roots more than in shoots although some sodium was in old parts of the shoot.

Seeds of *A. confertifolia* plants were collected in the Mojave Desert and from these seedlings rooted cuttings were prepared in large numbers. Some

Table 5. Yields and mineral composition of A. canescens grown in nutrient solution for 71 days (dry weight basis).

Treatment variables	Yield g	P %	Na %	K %	Ca %	Mg %	Zn ppm	Cu ppm	Fe ppm	Mn ppm	B ppm	Mo ppm	Sr ppm	Ba ppm
						Leaves								
Control	6.4	.54	.17	8.3	.78	.44	55	6	95	84	24	6.9	1	1
1/20 P	4.7	.17	.20	7.9	.79	.48	77	10	140	96	27	5.9	1	2
No Fe	.9	1.20	.11	8.4	1.09	.77	200+	35	9	342	29	9.3	2	3
1/20 K	3.3	1.65	.22	2.4	.84	.85	144	9	40	164	35	8.8	2	1
1/10 N	2.6	.52	.20	8.6	1.04	.60	45	9	92	108	25	8.9	5	2
No Zn	6.9	.41	.20	7.3	.92	.46	37	5	30	65	27	7.7	2	1
1/10 Mg	8.5	.66	.20	10.0	.62	.17	82	7	107	106	23	6.7	1	2
Na	11.5	.49	.28	5.4	.82	.45	48	4	57	61	26	6.9	2	1
1/10 N + Na	1.3	.63	.30	6.7	1.44	.66	72	26	124	126	35	13.6	10	11
NH_4NO_3	5.2	.67	.20	6.2	.66	.44	85	5	290	106	29	5.8	2	1
Urea	3.6	.49	.18	8.0	.54	.37	65	13	26	64	40	4.7	3	2
NH_4^+ + $CaCO_3$	1.0	.44	.19	8.0	1.07	.37	30	12	44	33	37	6.0	3	3
						Stems								
Control	4.3	.53	.02	5.6	.99	.23	5	12	45	70	18	2.9	5	1
1/20 P	2.4	.18	.02	2.6	.36	.15	5	7	36	87	9	0.7	2	1
No Fe	.2	.58	.02	1.8	.68	.20	27	10	3	115	12	1.5	5	3
1/20 K	1.8	.52	.12	1.7	.64	.17	25	10	25	95	12	3.0	3	1
1/10 N	2.4	.36	.02	1.7	.34	.13	5	7	22	44	10	1.0	4	2
No Zn	6.4	.30	.01	1.9	.37	.12	6	17	10	39	9	0.9	2	1
1/10 Mg	2.2	.45	.03	2.4	.59	.08	5	8	21	78	12	1.4	3	2
Na	5.9	.30	.07	2.3	.50	.19	7	5	19	47	13	2.3	3	1
1/10 N + Na	1.4	.52	.14	2.8	.44	.28	65	35	53	98	16	2.4	10	10
NH_4NO_3	3.0	.40	.02	2.1	.35	.13	18	5	47	76	11	1.6	2	1
Urea	0.7	.53	.02	3.5	.41	.15	8	10	8	27	17	1.2	6	2
NH_4^+ + $CaCO_3$	0.4	.25	.06	4.3	.66	.13	17	10	8	43	19	1.7	4	1

Continued on next page.

Treatment variables	Yield g	P %	Na %	K %	Ca %	Mg %	Zn ppm	Cu ppm	Fe ppm	Mn ppm	B ppm	Mo ppm	Sr ppm	Ba ppm
Roots														
Control	1.08	1.01	.13	3.6	.22	.43	32	20	1517	110	15	14.8	2	15
1/20 P	1.15	.31	.06	3.6	.12	.42	21	17	879	86	13	7.3	2	18
No Fe	.12	.61	.07	3.9	.20	.42	124	18	412	143	14	27.7	3	37
1/20 K	.41	1.34	.20	.9	.96	.42	74	34	1520	245	17	18.5	3	16
1/10 N	.69	.84	19	3.1	.28	.43	22	20	1415	69	13	20.0	5	40
No Zn	1.10	.57	.19	3.4	.30	.49	5	13	717	72	15	6.4	3	15
1/10 Mg	.60	.60	.20	3.6	.44	.30	49	20	1086	68	16	14.8	3	12
Na	1.68	77	20	1.9	.36	.59	15	18	1224	202	20	6.8	4	20
1/10 N + Na	.58	.66	.20	3.2	.18	.50	25	20	870	60	12	11.2	5	30
NH_4NO_3	.65	.60	.12	2.6	.24	.34	8	12	1120	63	16	25.6	3	7
Urea	.26	.94	.08	1.0	.80	.17	149	13	278	139	3	3.2	3	6
NH_4^+ + $CaCO_3$	.14	.55	.12	4.4	.80	.54	76	38	400	115	21	5.1	5	13

Table 6. Sodium contents in parts of A. canescens plants grown in nutrient solution plus different levels of Na_2SO_4.

Plant parts	me Na_2SO_4 per liter		
	0	10	90
	% of dry weight		
Young leaves	0.19	0.23	0.84
Young stems	0.13	0.16	0.35
Old leaves	0.17	0.20	0.55
Old stems	0.04	0.09	0.09
Roots	0.67	2.19	3.18

of these growing in small cups of soil were barerooted, washed, and transferred to 500 ml nutrient solutions for a period of 76 days. Culture solution treatments were listed in Table 4. Plants were harvested and processed as previously indicated for A. canescens. The date for A. confertifolia are in Table 7. The cuttings had been grown in tap water before transferring to nutrient solution and contained considerable sodium without additional sodium treatments. The addition of sodium, however, did greatly increase sodium content of leaves but much less so of stems and roots. Roots contained very small quantities of sodium relative to leaves and a sharp gradient existed from leaves to stems to roots. When nitrogen was adequate, there was a relatively large yield increase from the sodium. This could be either a so-called agricultural response (Leonard, 1950) or could be an indication of a sodium requirement (Brownell, 1965, 1968). Further studies are necessary to determine which. Potassium contents of plants were high, so that sodium response most likely was not a partial replacement of potassium by sodium (Wallace, 1948).

A. confertifolia cuttings grew better at 21°C soil temperature than at 33°C and growth at both of these temperatures was much better than at 11°C (Table 8). On the other hand A. canescens grew best at 33°C soil temperature for 75 days in Yolo loam, intermediate at 21°C soil temperature, and least at the low soil temperature (11°C). The difference between the two species for maximum response to soil temperature conditions may explain in part their distribution in the field. Additional tests wherein both air and root temperatures were varied showed some interesting interactions by A. confertifolia (Figure 13). At 15°C air temperature, highest yield was at 25°C root temperature. At 25°C air temperature the yield was highest at 35°C root temperature. This effect was overcome at 35°C air temperature where highest yields occurred at the two lower root temperatures.

Cuttings of desert holly (A. hymenelytra) were made from seedlings (Figure 6) germinated from a commercial supply of seed. They rooted readily in a semi-humid glasshouse without special treatment, either in soil or vermiculite. The cuttings were transplanted to Yolo loam soil in 4 liter pots and when about 20 cm tall, 27 of them were selected for a study with NaCl treatments applied directly to the soil. Three applications of NaCl (0, 1g, 5g per pot) were made 1 week apart at the beginning of the experiment. Nitrogen as $Ca(NO_3)_2$ was added at the rate of 25 me per pot in 5 equal weekly applications. No other nutrients were added. The results of this test are summarized in Table 9. Yields of plants were not influenced by the salt treatments. Salt treatments greatly increased sodium content of leaves but not of roots. A sharp gradient was observed for sodium content from top leaves to roots with stems interme-

Table 7. Yields and mineral composition of A. confertifolia when grown in various nutrient solutions (dry weight basis).

Treatment	Yield g	P %	Na %	K %	Mg %	Ca %	Zn ppm	Cu ppm	Fe ppm	Mn ppm	B ppm	Co ppm	Ni ppm	Mo ppm	Cr ppm
Leaves															
Control	1.04	1.25	1.35	9.52+	.47	.61	167	14	143	85	31	.3	4.4	4.3	.4
1/20 P	1.08	.45	1.10	9.99+	.51	.88	178	10	155	46	30	.2	2.0	5.8	.1
No Fe	.75	1.41	.29	9.99+	.59	.53	200+	36	46	146	26	.2	4.6	5.6	.4
1/20 K	.54	1.59	3.44	3.37	.72	.90	200+	30	99	209	30	.3	3.1	4.1	.4
1/10 N	.39	1.14	2.70	9.99+	.44	.51	200+	21	67	116	25	.3	1.8	4.7	.4
No Zn	1.41	1.30	1.24	8.76	.40	.32	200+	9	59	84	25	.1	4.0	4.3	.3
1/10 Mg	1.21	1.06	.79	8.09	.16	.58	174	14	166	99	30	.6	5.0	3.6	.4
Na	2.30	1.12	5.90	6.06	.28	.49	167	12	125	52	31	.1	5.9	4.7	.3
1/10 N + Na	.47	1.21	6.18	6.63	.26	.22	200+	21	52	87	14	.5	1.6	5.9	.4
NH_4NO_3	1.25	1.16	1.53	8.13	.39	.48	169	13	57	62	32	.3	4.5	4.5	.4
Urea	1.51	.94	1.39	7.53	.32	.43	146	11	65	124	17	.4	2.0	5.3	.6
$NH_4^+ + CaCO_3$	1.23	1.22	1.81	9.99+	.46	.28	200+	16	47	170	17	.2	2.2	3.4	.3
Stems															
Control	.45	.62	.05	4.44	.26	.52	145	9	54	77	29	.5	4.0	2.1	<0.1
1/20 P	.59	.43	.05	3.20	.21	.79	154	5	46	48	35	.7	5.3	12.6	<0.1
No Fe	.29	.50	.05	4.08	.27	.66	165	19	17	68	46	.3	4.7	1.8	<0.1
1/20 K	.19	.88	.36	3.71	.31	.66	200	13	37	92	28	.1	3.8	2.8	<0.1
1/10 N	.18	.61	.22	4.87	.27	.53	123	12	57	63	22	.1	2.2	3.8	<0.1
No Zn	.75	.67	.05	4.14	.23	.38	200	5	30	55	27	.8	3.3	1.1	<0.1
1/10 Mg	.57	.56	.12	3.41	.11	.61	161	8	42	76	24	.8	3.7	1.5	<0.1
Na	1.17	.51	.39	2.55	.23	.36	128	6	38	69	28	1.4	5.0	2.3	<0.1
1/10 N + Na	.22	.49	1.02	3.02	.21	.33	141	7	50	59	23	1.6	3.9	1.9	<0.1
NH_4NO_3	.54	.57	.07	3.00	.17	.30	155	6	24	56	25	1.1	3.3	1.4	<0.1
Urea	.46	1.18	.05	7.59	.28	.45	154	8	29	84	36	.9	5.7	2.1	<0.1
$NH_4^+ + CaCO_3$	.39	1.20	.10	8.08	.28	.29	200	9	20	93	27	1.0	6.4	2.2	<0.1

Table 7 continued.

Treatment	Yield g	P %	Na %	K %	Mg %	Ca %	Zn ppm	Cu ppm	Fe ppm	Mn ppm	B ppm	Co ppm	Ni ppm	Mo ppm	Cr ppm
						Roots									
Control	.14	1.00	.05	3.06	.26	.12	200+	24	1600	162	18	4.2	2.7	23.4	0.1
1/20 P	.19	.51	.05	1.16	.12	.22	200+	24	1140	63	16	4.7	1.0	14.0	0.1
No Fe	.10	.87	.16	1.81	.53	.27	200+	17	155	110	19	3.4	3.6	19.9	1.3
1/20 K	.09	1.18	.05	3.14	.44	.21	200+	32	2019	95	23	5.0	6.0	31.2	<0.1
1/10 N	.17	.79	.05	4.17	.39	.10	200+	33	1603	114	14	1.0	4.9	18.7	<0.1
No Zn	.22	.67	.05	4.23	.37	.11	200+	21	1700	155	16	2.1	5.6	14.4	<0.1
1/10 Mg	.18	.55	.05	4.16	.18	.11	200+	25	1212	195	16	2.7	6.1	19.2	<0.1
Na	.45	.73	.21	2.15	.31	.05	200+	14	1152	154	16	3.5	5.0	14.5	<0.1
1/10 N + Na	.19	.63	.73	1.56	.29	.12	200+	24	1155	105	17	3.0	3.1	17.3	<0.1
NH_4NO_3	.11	.63	.05	2.57	.24	.09	200+	24	1820	139	19	3.6	5.4	25.0	<0.1
Urea	.22	.48	.05	2.63	.36	.10	200+	17	793	151	21	3.5	4.8	5.3	<0.1
$NH_4^+ + CaCO_3$	.11	.52	.07	3.29	.50	.09	200+	27	576	173	15	4.4	8.1	2.3	<0.1

Table 8. Response of *A. confertifolia* cuttings to soil temperature and mineral composition of the plants on the dry weight basis.

Soil temp. °C	Dry wt mg	P %	Na %	K %	Ca %	Mg %	Zn ppm	Cu ppm	Fe ppm	Mn ppm	B ppm	Mo ppm	Sr ppm	Ba ppm
11	750	1.34	.20	>10	.88	.72	157	47	122	325	160	6.1	32	52
21	4040	1.39	.11	>10	1.10	.77	200	59	341	411	109	7.8	44	72
33	3200	1.37	.20	>10	1.38	.77	200	63	528	435	130	7.7	56	106

Table 9. Yields and mineral composition of plant parts of *A. hymenelytra* grown in soil at 3 different levels of sodium chloride.* (Dry weight basis.)

Treatment	Plant parts	Na	K	Ca	Mg	Cl	P	Zn	Cu	Mn	B	Fe
Na level		%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm
0	Top leaf	2.18	9.64	.73	.62	.63	.84	124	34	190	46	48
	Middle leaf	3.08	9.52	.71	.65	.66	1.33	153	44	230	44	49
	Bottom leaf	3.17	9.98	.72	.64	-	1.50	154	53	212	40	74
	Top stem	0.33	8.59	1.03	.42	.49	.55	87	13	125	25	15
	Middle stem	0.23	4.95	1.04	.33	.39	.61	72	15	147	23	12
	Bottom stem	0.05	2.42	0.99	.27	.08	.50	70	18	197	14	19
	Root	0.05	1.98	0.92	.33	.18	.40	56	31	286	13	399
1	Top leaf	8.32	9.33	0.72	.48	9.95	.87	150	34	241	37	46
	Middle leaf	8.32	9.45	0.94	.56	9.81	1.26	185	41	281	39	58
	Bottom leaf	7.40	9.15	0.72	.51	8.66	1.31	155	44	256	35	77
	Top stem	3.82	6.75	1.28	.35	3.44	.61	56	13	158	25	17
	Middle stem	1.67	4.95	1.09	.27	1.38	.58	77	16	193	21	16
	Bottom stem	0.11	2.60	1.16	.25	.73	.59	79	20	255	15	30
	Root	0.05	2.20	1.06	.35	.76	.45	55	29	317	13	439
5	Top leaf	9.52	9.72	0.66	.47	9.45	.86	161	38	233	27	49
	Middle leaf	9.16	9.31	0.90	.51	8.15	1.02	152	41	267	34	51
	Bottom leaf	8.74	9.73	0.78	.54	6.49	1.07	160	44	251	33	59
	Top stem	5.09	7.22	1.19	.29	5.30	.55	81	15	131	23	18
	Middle stem	2.90	5.38	1.19	.29	2.78	.51	78	18	172	23	17
	Bottom stem	0.62	3.03	1.22	.26	1.28	.50	66	25	227	21	25
	Root	0.10	2.58	.99	.39	.61	.42	65	30	346	13	498

*Means of 9 plants. Total dry plant weight: 0 Na = 13.2 ± 1.4; 1 Na = 13.3 ± 1.3; 5 Na = 12.1 ± 1.8.

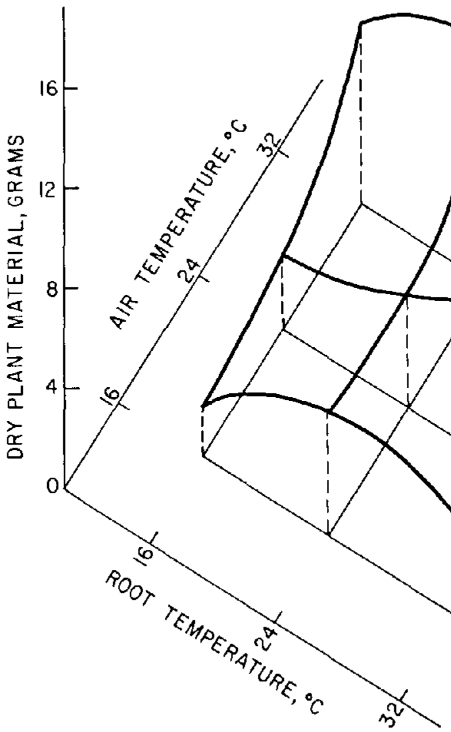


Figure 13. A. confertifolia growth response to variations in air and soil temperature.

diate. The high concentrations of sodium in leaves indicate possible presence of salt glands. A microscopic examination of the leaf structure indicates a thin layer of green palisade cells surrounded on both top and bottom by a heavy relatively wide cork layer. Within the cork layer salt glands may be located, but we have not confirmed this as yet. Chatterton et al. (1970) suggest that most of the absorbed salt by A. polycarpa may be localized in the trichomes and therefore essentially isolated from the mesophyll tissues. A potassium gradient in the plants somewhat similar to that of sodium was observed. Chlorine behaved similarly. This occurred for each salt treatment. At the high salt level, top leaves contained nearly 10% on the dry weight basis of sodium, chlorine, and potassium. Leaves had very high levels of phosphorus and zinc but they were low in boron. This species is supposedly tolerant of high boron levels; low uptake may be the reason. Calcium contents of stems were higher than that of leaves. Magnesium levels were higher than for most plant species.

The low sodium contents of roots was noteworthy. In contrast to bush beans, which do retain sodium, the A. hymenelytra roots retained virtually none. The high degree of tolerance of this species for sodium seems to be related to its ability to transport it from roots, where it is not stored, to inactive sites in leaves as indicated by leaf anatomy studies.

Growth response of A. hymenelytra to air and root temperatures is shown

Table 10. Mineral composition of leaves of *A. confertifolia*, *A. canescens*, and *A. hymenelytra* grown at or near the N. T. S.

Location	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
	% of dry weight						ppm of dry weight											
							A. confertifolia											
Frenchman Flat A	.21	5.82	7.92	2.73	.78	.15	5	4	206	85	60	334	16	3.4	1.0	1.3	65	22
B	.33	4.34	9.36	1.87	.62	.19	24	6	240	75	74	409	38	6.0	0.5	0.5	77	46
C	.31	3.78	6.50	2.65	.67	.16	5	4	207	58	90	396	19	7.0	1.6	2.4	92	45
D	.39	5.16	5.12	1.45	.52	.35	20	3	453	46	42	826	239	1.5	0.5	0.7	60	29
Red Mt.	.30	5.22	6.11	2.65	.55	.19	5	3	228	78	62	469	46	2.7	1.5	2.3	97	29
Near Mercury	.53	4.51	7.00	1.18	.88	.16	119	9	278	96	40	136	35	1.5	0.7	1.3	41	21
Rock Valley	.51	5.49	7.81	2.80	.58	.32	2	4	406	89	59	795	93	2.1	1.1	1.8	116	35
							A. canescens											
Yucca Flat	.38	0.07	7.98	2.55	0.68	.22	4	5	278	110	64	576	69	4.1	1.7	4.0	67	19
Frenchman Creek	.32	0.72	10.30	2.32	1.04	.24	3	5	285	85	60	491	39	6.1	1.2	1.7	112	63
Indian Springs	.26	0.18	7.50	2.47	0.83	.13	2	5	216	90	106	357	25	6.6	1.0	1.3	103	67
							A. hymenelytra											
Shoshone	.12	8.76	7.14	0.98	.62	.05	11	3	164	96	192	179	11	4.3	1.2	1.6	114	39
Parump	.27	8.54	13.16	1.44	.44	.16	18	6	288	69	1588	439	38	4.6	1.0	1.2	96	17
State line	.14	9.84	8.15	1.61	.82	.04	6	5	148	57	302	164	27	3.0	1.0	0.7	98	15

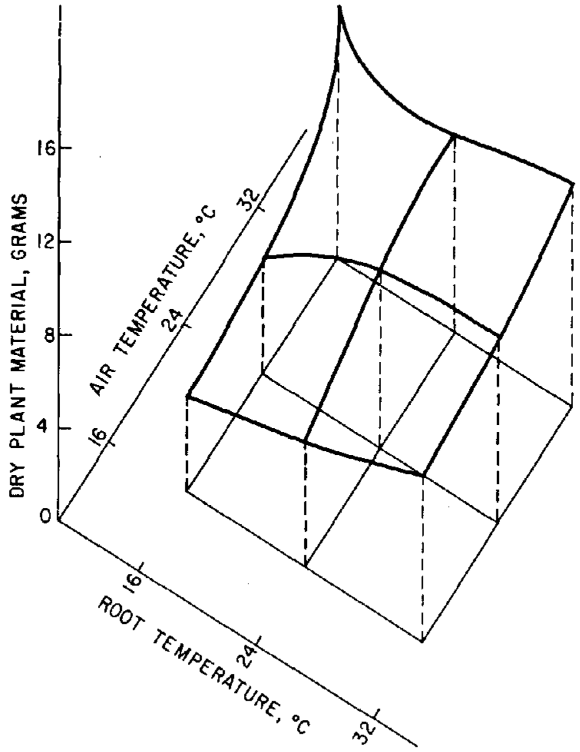
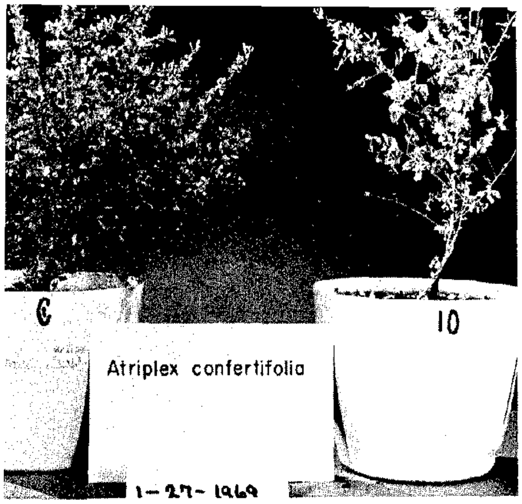


Figure 14. A. hymenelytra growth response to variations in air and soil temperature.

in Figure 14. This species grows best at high air and soil temperatures which one might expect since it naturally occurs in areas more conducive to having these extreme environmental conditions.

A. confertifolia (Figure 15) was slightly more susceptible to gamma radiation from a ^{60}Co source than was A. canescens (Figure 16). Repeated tests indicated that the lethal dose for A. confertifolia was 6 to 7 kR and for A. canescens, 10 to 11 kR. Plant response to an acute dose (single intense exposure) is evidenced by cessation of growth, yellowing and wilting of foliage, then defoliation—all of which progressively occur over a 3 to 6 week period.

Mineral composition of leaves of plants grown in the field is given in Table 10. As is well known, sodium contents of A. confertifolia and A. hymenelytra were much higher than that of A. canescens. Zinc and copper contents generally were low in all three species. The potassium contents were high as also occurs when these species are grown under laboratory conditions. Silicon contents of leaves were higher than for most species. It is not known if this contributes to drought tolerance.



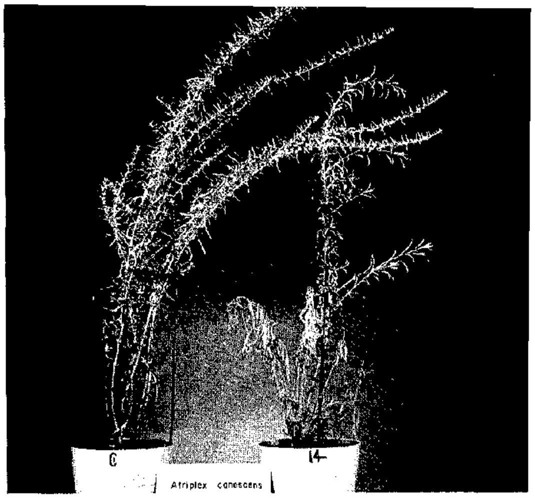


Figure 15. (left) Response of *A. confertifolia* to acute gamma radiation from ^{60}Co source; lethal dose range 6 to 7 kR.

Figure 16. (right) Effects of an acute dose of gamma radiation on *A. canescens*; lethal dose 10 to 11 kR.

Summary

Growth of *A. confertifolia* in solution culture appeared to respond to sodium, at least when other nutrients were not limiting. The yield response was obtained in the presence of a relatively high level of potassium. The potassium content of foliage of plants responding to sodium was over 5% of dry weight. A sharp gradient of sodium and potassium content exists in *A. confertifolia* and *A. hymenelytra* with leaves higher than stems, and stem higher than roots. A major peculiarity of laboratory grown *A. confertifolia* plants was a high zinc content of leaves, stems, and roots, although this did not hold for field-grown plants. Yields were also increased by sodium for *A. canescens*, but sodium and potassium contents were much lower than for *A. confertifolia* and the leaf-stem-root gradient was poorly pronounced and in one case reversed. *A. canescens* seemed to be resistant to absorption of large quantities of sodium. *A. canescens* was slightly sensitive to low soil pH, but seemed insensitive to the presence or absence of $CaCO_3$ in the soil. *A. canescens* had a higher soil temperature optimum than *A. confertifolia* and this may explain its wider distribution, especially into the hot deserts. Cuttings of *A. confertifolia*, *A. canescens*, and *A. hymenelytra* rooted, but *A. confertifolia* seems to lose this ability as shoots become old. *A. canescens* is more widespread than other *Atriplex* species, and may be more tolerant of high salt levels than *A. confertifolia.*

Mineral composition of field-grown plants indicated that *A. canescens* leaves contained much lower contents of sodium than leaves of *A. confertifolia* or *A. hymenelytra*. *A. confertifolia* was slightly more sensitive to gamma irradiation than was *A. canescens*. Silicon contents are higher than for most species.

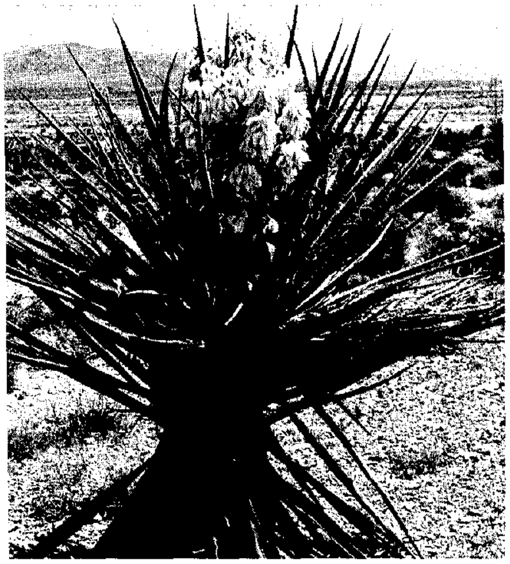
Note: A recent report indicates that yield responses due to salt with *Atriplex* occur with low humidity but not with high humidity; it is a matter of salt overcoming high evaporative demand (Gale et al., Aust. J. Biol. Sci. 23:947-952, 1970).

CHARACTERISTICS OF YUCCA SPECIES
Y. SCHIDIGERA, Y. BREVIFOLIA, AND Y. BACCATA

Yucca schidigera Roezl ex Ortgies (Figure 1) is a common consituent of Larrea communities in south Frenchman Flat and in many other valleys of the Nevada Test Site (Beatley, 1969). It occurs between 900 - 1100 m in southern Nevada. Yucca brevifolia Engelm. in Wats., (Figure 2) occurs at slightly higher elevation than Y. schidigera. According to Beatley it occurs in upper Larrea, Grayia-Lycium, and lower Coleogyne associations (Beatley, 1965). Yucca baccata Torr., in Emory (Figure 3), occurs at elevations of around 1500-2100 m (Beatley, 1969).

Shreve and Wiggins describe these three species as follows (Shreve and Wiggins, 1964):

> Yucca schidigera Roezl ex Ortgies, Gartenfl. 20:110, 1871.
>
> Shrub or small tree 1 - 5 m high; trunk simple or branched above, 15 - 25 cm in diameter; leaves 30 - 50 cm long, 3 - 4 cm wide, concave, smooth, stout-pungent at apex, coarsely filiferous along grayish to light brown margins; inflorescence a crowded, erect, sessile or short-scapose panicle 4 - 6 dm high; perianth segments creamy white or lightly tinged with purple, 2.5 - 4.5 cm long, acute filaments slender, glabrous except at apex, there somewhat puberulent, equaling pistil; style 0.5 - 2



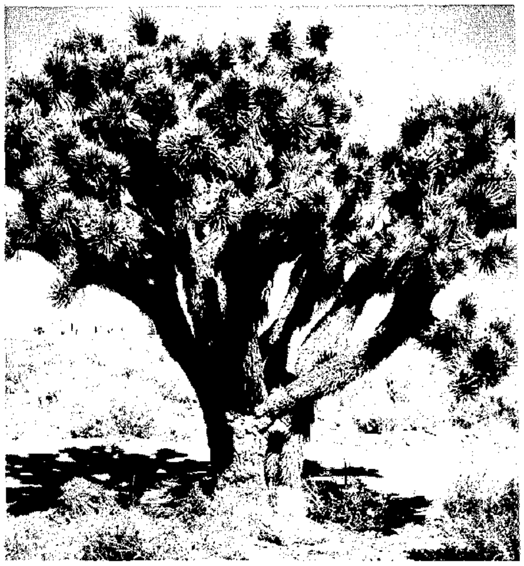


Figure 1. (left) Y. schidigera in bloom in Mercury Valley. It grows at elevations from 900 to 1100 in southern Nevada. This plant is over 30 years old.

Figure 2. (right) Y. brevifolia a monocotyledonous tree prominent in the Mojave Desert. It grows at elevations from 1000 to 1500 m at the Nevada Test Site. This plant is over 200 years old.

mm long, pistil 1.5 - 2 cm long at anthesis; fruit 5 - 10 cm long, narrowly ovoid to oblong, often variously constricted, baccate, with white, sweetish flesh; seed black, lustrous.

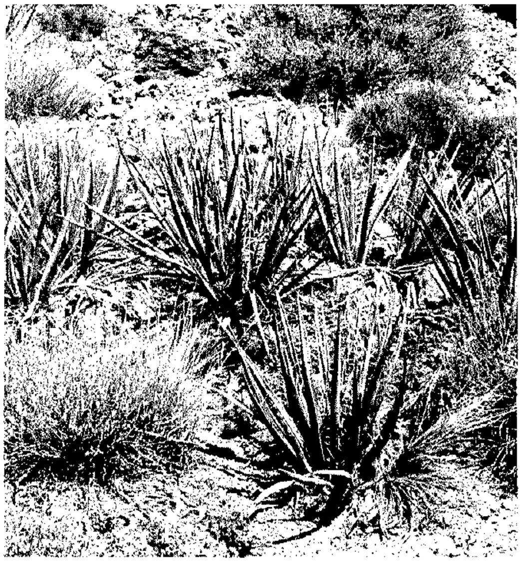
Arid hills and along desert washes, Lower and Upper Sonoran Zones, San Diego County, California, to southern Nevada, western Arizona, and northern Baja California. March - April.

Yucca brevifolia Engelm., in S. Wats., Bot. King Expl. 496, 1871.

Tree 5 - 12 m high with a roughened trunk 5 - 9 dm in diameter and openly branched to form a rounded head in older trees, young trees unbranched and clothed to the ground with persistent, reflexed leaves; leaves rigid, sharp-pointed, radiately spreading at ends of branches, 10 - 15 mm wide, 15 - 30 cm long, somewhat 3-sided, minutely but sharply denticulate; panicle sessile, dense, 25 - 40 cm high, erect, branches often short-hispid; flowers oblong to subglobose, greenish white, perianth segments 25 - 30 mm long; fruit ovoid, 5 - 10 cm long, 2 - 4.5 cm in diameter, indehiscent, dry and spongy; seeds flattened, obovate to nearly orbicular, 7 - 8 mm long, black, dull to somewhat lustrous.

Desert slopes and hillsides, Lower Sonoran Zone, mostly in the Mojave Desert but occasionally entering the extreme northern part of the Sonoran Desert near Needles, California. March - May.

Yucca baccata Torr., in Emory, Bot. Mex. Bound. 221, 1859. var. *baccata*.



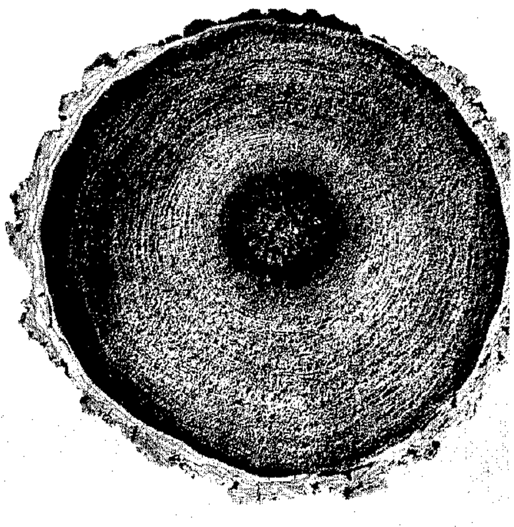


Figure 3. (left) *Y. baccata* which grows at elevations of 1500 to 2000 m at the Nevada Test Site.

Figure 4. (right) Ring structure appearance in base stem of *Y. brevifolia.*

Plant usually simple but sometimes in clumps of 2 - 6 individuals; stems very short or to 1 m long and procumbent; leaves 5 - 7.5 dm long, 2.5 - 4 cm wide at about middle, tapering gradually to apex and narrowed slightly toward base, usually somewhat twisted or falcate, rigid except near union with basal part, scabrous on both surfaces, blue-green or yellow-green, moderately glaucous; leaf margins separating into coarse, flattish fibers along upper half of leaf, persistent fibers 1 - 10 cm long, recurved; terminal spine 1.5 - 7 cm long, stiff; scape 10 - 15 cm long, stoutish; inflorescence to 7.5 dm tall, 2.5 - 4.5 dm. in diameter, ovoid; pedicels 7 - 40 mm long; flowers 5 - 15 cm long, campanulate, perianth segments expanding only slightly in anthesis, fleshy, denticulate along margins, inner 4 - 5 mm wider than outer ones; stamens 3 - 4.5 cm long, clavate tip nearly horizontal at anthesis; pistil 5 - 8 cm long; style 5 - 7 mm long; fruit fleshy, 12 - 17 cm long, 5 - 6.5 cm in diameter at base, tapering toward apex.

Desert slopes and mountainsides, Lower and Upper Sonoran Zones, eastern Mojave Desert, California, to southwestern Colorado and south into central Arizona, most of New Mexico, and southwestern Texas. April - July.

Species of Yucca attain fairly old age. New growth in *Y. schidigera* occurs via production of 6 new leaf blades at a time. On specimens on which old growth was identified with a thin coating of water-based paint, either 2 or 3 sets of new leaves per plant were produced in 1967. Three sets were produced in 1968; two to four were produced in 1969. Using these as averages, and by counting leaf blades, the age of some of the individuals in Mercury Valley approaches 200 years.

Yucca brevifolia, even though a monocot, has annual growth rings because it has a peculiar cambium layer. This layer, however, does not produce new xylem on the inside and phloem on the outside, but produces on the inner side a succession of new "closed" bundles of small size, each containing both xylem and phloem tissue (Holman and Robbins, 1939). These give a ring structure appearance to a cross section of a *Y. brevifolia* stem.

Y. brevifolia growth rings can be easily counted in the base of the shoot (Figure 4). The base of the shoot has bark and evidently a cambium layer. On one very young plant we counted 120 leaf blades or 20 sets of 6 as was the case in *Y. schidigera*. The stem had 12 "growth" rings; if these were annual rings it would then have had 1 2/3 sets of new leaf blades per year. Another large plant had 28 "growth" rings; it had 188 green blades, 200 dead blades, and the calculated length of the remaining bared stem from which leaf blades had dropped would involve space (0.45 cm per 6 blades) for 100 more previous blades as an estimate. This averages 17 blades per "growth" ring or roughly 3 sets per "growth" ring. We know that in a favorable year more than 3 sets of 6 blades can be developed. In 1969 from 6 to 8 sets of 6 blades were developed on *Y. brevifolia* due to the large amount of rain. In some years fewer than 3 sets are developed but the average seems to be around 3. This would indicate the feasibility of estimating age either by leaf blade count or from height of plants ($1\frac{1}{2}$ cm per year). Accordingly, some of the mature *Y. brevifolia* in Yucca Flat would exceed 200 years of age. Campbell and Keller (1932) reported that *Yucca elata* grew at an average rate of $2\frac{1}{2}$ cm per year from which age could be estimated. *Y. brevifolia* and *Y. schidigera* grow at about $1\frac{1}{2}$ cm per year.

Y. schidigera does not flower every year. Recent years favorable for flow-

Figure 5. Pack rat nest at the base of Y. schidigera. Note how rats chew on the leaves of this shrub.

ering at the Nevada Test Site have been 1961, 1966, 1969. If a new shoot does not form at the side, the old stalk may die and a new shoot will form at the base. This results in the characteristic multishoot individuals having live and dead stalks. In Y. brevifolia, new stalks grow from the side of the old flower to give the characteristic branched form in this species. Cattle graze on Yucca blossoms when the blossoms can be reached.

Pack rats build nests around the base of Y. schidigera and pile up large quantities of pebbles and debris in the process (Figure 5). They use the succulent leaf blades of this shrub for food and/or water.

Experimental Results

Young seedlings of the Yucca species are relatively sparse in the field study areas. Germination appears to occur readily; however, seedling survival appears to be dependent upon a consecutive sequence of favorable climatic conditions, once germination has occurred. The presence of distinct ranks of Y. brevifolia representing a common age among the population would indicate that successful new seedling establishment might occur only a few times during a given century (Table 1). This period of sensitivity for seedling survival in the field appears to be from three to five years duration (Figure 6). At sprinkler-irrigated study plots near Mercury, Nevada, we found markedly greater survival of Y. schidigera seedlings after three years of supplemental moisture than occurred in the adjacent non-irrigated plots.

The data in Table 1 are of considerable interest in that they indicate sufficient young shrub survival in the field to maintain the plant population. The total number of individuals in these ranked heights (0.5 m increments) were surprisingly uniform when less than 3 m tall. The reduced numbers of taller, and presumably older, shrubs suggest that height may not be a valid estimate for aging very mature plants. These taller shrubs engage in much subbranching, and we counted as many as 76 branch apexes on plants greater than four m tall. Among the 347 total individuals growing in the 30 x 180 m transect area, there were remains of 72 dead plants in various stages of decay. Five had died so recently that their leaves were still solidly attached, but more than half of them were in very advanced stages of decay. The increasing sparsity

Table 1. Size distribution of Y. brevifolia population in plots transecting a bajada in southwestern Yucca Flat.

	Number of shrubs ranked in height (meters)									
Plot*	0-.5	.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5
(Upper bajada in climax vegetation)										
1	4	4	1	2	1	3	3	5	1	1
2	6	9	5	1	0	3	2	4	1	0
3	1	8	3	2	3	2	4	6	0	1
4	3	7	4	1	1	2	7	5	1	1
5	1	2	4	5	3	1	1	3	5	2
6	10	5	9	14	9	11	5	1	1	0
7	13	7	8	6	6	9	1	3	2	2
8	6	1	8	6	6	9	1	2	2	1
9	1	0	3	0	4	7	2	0	0	1
10	4	4	3	1	8	2	1	0	0	0
(Lower bajada demarcation line)										
Total	48	47	48	38	41	49	27	29	21	8

*A census was made of Y. brevifolia in a transect 30 m wide by 1800 m long down a bajada in southwestern Yucca Flat. The transect extended from well into the climax stand down the slope onto the playa where Y. brevifolia ceases to grow. Shrubs growing in adjacent plots, 30 x 180 m, were ranked according to height in 0.5 m increments.

of mature shrubs near the lower bajada demarcation line suggests either that Y. brevifolia might be advancing from the bajada onto the playa or the edaphic and/or climatic factors prevent shrubs from reaching advanced states of maturity nearer the playa.

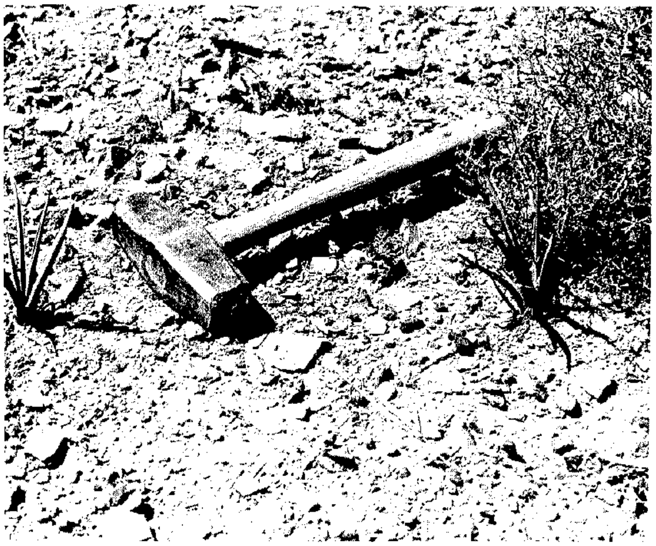


Figure 6. New Y. brevifolia seedlings growing in western Yucca Flat basin. These seedlings are from 3 to 5 years old.

Table 2. Mineral composition of leaf blades from Y. brevifolia from Yucca Flat.

Age of blades	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
Year			% of dry weight								ppm of dry weight							
1	.41	.003	1.17	1.08	.41	.04	18	13	92	17	11	131	2	.5	.7	7	79	18
3	.29	.02	1.59	1.43	.53	.10	10	18	173	52	13	191	4	.5	.8	3	79	17
20	.10	.02	.61	1.60	.40	.18	—	16	240	51	21	379	17	.5	.5	52	78	16

Table 3. Mineral composition of shoots of Y. schidigera and Y. brevifolia grown in Yolo loam soil at different root temperatures.

Temp.	Yield g	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
°C				% of dry weight								ppm of dry weight							
							Y. schidigera (180 days)												
10	3.44	.78	.20	3.29	2.13	.75	.58	<5	5	642	96	37	1074	130	3.7	<.5	2.0	76	164
18	23.05	.57	.50	2.94	3.25	.81	.17	<5	8	242	99	108	471	25	4.1	<.5	2.3	98	157
35	9.81	.74	.29	3.57	2.36	.66	.72	<5	12	594	89	73	1494	214	1.2	<.5	4.0	84	211
							Y. brevifolia (90 days)												
16	.86	.22	.10	4.28	1.55	.43	.40	18	5	457	48	38	725	78	1.8	<.5	4.1	59	86
21	1.57	.41	.10	3.97	1.11	.44	.62	23	6	735	81	46	1296	327	1.5	<.5	5.5	53	157
28	.95	.58	.16	3.35	1.14	.53	.98	8	9	641	86	46	1296	545	1.4	<.5	5.8	50	171

The mineral composition of field-grown Y. brevifolia leaves is shown in Table 2. Phosphorus and potassium contents of leaf blades decreased with age, while sodium, calcium, silicon, iron, boron, aluminum, and titanium increased with age. Content of sodium was small.

Seeds of Y. brevifolia and Y. schidigera germinate readily in artificial environments. The seedlings of these species seem to prefer a soil temperature of 18°C over 10°C or 35°C. Of most interest was the great effect that soil temperature had on the relative growth of top to root as shown in Figure 7 for Y. schidigera. The proportion that was root decreased greatly with increasing soil temperature. Results are indicative of a temperature-related root-produced regulator. Yields of Y. schidigera plants grown 6 months and of Y. brevifolia grown 3 months at different soil temperatures are in Table 3 along with mineral analyses.

Y. schidigera appeared to be sensitive to soil pH in that shoot weight decreased when grown for 90 days in Yolo loam soil with 10% added $CaCO_3$; micronutrient contents were related to soil pH (Table 4). Experiments with Y. brevifolia gave similar results. This fits the observation that it tends to grow in noncalcareous soil (Cannon, 1960). Calcium and molybdenum contents were reduced with decreasing soil pH. On the other hand potassium, phosphorus, copper, iron, manganese, and zinc increased with decreasing pH.

Table 4. Top yields and mineral composition on the dry weight basis of leaves of Y. schidigera grown in Yolo loam soil with and without excess $CaCO_3$ and sulfur.

Measurement	$CaCO_3$ (pH 7.5)	Control (pH 6.0)	Sulfur (pH 4.2)
Leaf wt, g/plant	0.61	1.65	1.52
Stem wt, g/plant	0.45	0.44	0.39
Ca, %	2.11	1.60	1.30
K, %	3.19	3.95	4.17
Mg, %	0.58	0.57	0.54
Na, %	> 0.20	> 0.20	0.16
P, %	0.18	0.45	0.59
B, ppm	38	26	29
Cu, ppm	7	12	20
Fe, ppm	107	181	278
Mn, ppm	41	66	273
Co, ppm	Trace	Trace	1.8
Mo, ppm	6.4	2.5	1.2
Zn, ppm	8	5	17

Means of determination from 3 plants.

Y. schidigera seedlings were grown for 30 days in a complete nutrient solution, except for additions of Na_2SO_4 equivalent to 0, 1, 5, 10, and 30 me per liter in 1800 ml pots. Upon harvest the plants were washed in 1/10N HCl and water, dried, weighed and ground in preparation for spectrographic analysis. The results in Table 5 indicate that the Na_2SO_4 was not toxic, that Y. schidigera did not absorb large amounts of sodium, that sodium tended to remain in roots, that calcium contents were relatively low, that the metals zinc, copper, iron, manganese, and aluminum tended to concentrate in roots, that zinc con-

Table 5. Yields and mineral composition of *Y. schidigera* seedlings grown in solution culture with different levels of Na_2SO_4.

Na_2SO_4	Dry wt	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Al
me/l	g/plant	% of dry weight					ppm of dry weight					
					Whole-plant basis							
0	0.127	0.63	0.12	5.08	0.61	0.44	142	41	496	65	22	39
1	0.124	0.72	0.53	5.07	0.58	0.40	162	50	358	45	22	35
5	0.098	0.49	0.20	3.80	0.57	0.42	183	46	278	39	25	50
10	0.148	0.63	0.43	4.42	0.54	0.40	116	37	337	54	25	35
30	0.120	0.73	1.85	3.23	0.56	0.43	119	62	350	47	20	55
					Top							
0	0.074	0.57	0.02	3.50	0.89	0.51	113	12	95	33	30	16
					Root							
0	0.053	0.72	0.25	7.27	0.22	0.34	182	80	1049	110	11	71
					Top/root ratio							
0	1.40	0.79	0.08	0.48	4.05	1.50	0.62	0.15	0.09	0.30	2.73	0.23

Figure 7. Y. schidigera seedlings after 6 months growth at 10°C (left), 18°C (center), and 35°C (right) root temperature.

tents were relatively high.

Experiments with Y. brevifolia gave similar results except that Y. brevifolia absorbs less sodium than Y. schidigera and seems to be more tolerant of it. In the field this species seems to be distributed more into valleys than Y. schidigera, and its salt tolerance may be the reason.

Y. schidigera seedlings were irradiated with an acute dose of gamma radiation from the 10,000 curie ^{60}Co source at levels of 0, 4, 8, 12, 16, 20, 24, 28, 32, and 36 kR to test tolerance of this species to ionizing radiation. The seedlings were then planted into 3 kg of Yolo loam soil and grown for 1 year with periodic applications of nitrogen fertilizer. Upon harvest they were photographed (Figure 8), weighed and assayed by emission spectrography for mineral contents. The lower levels of radiation (4 - 12 kR) appeared to stimulate yields,

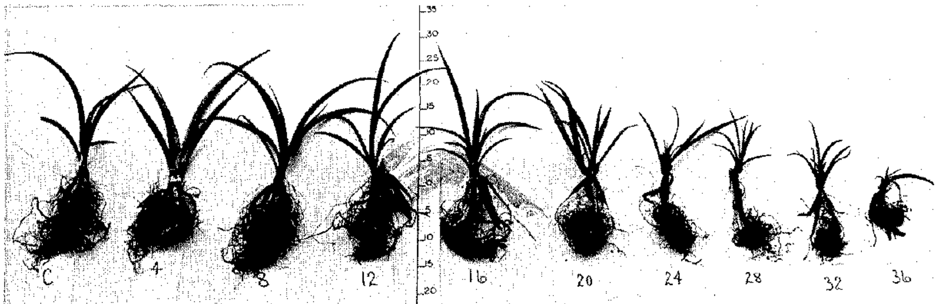


Figure 8. Growth of Y. schidigera one year after acute irradiation. from a ^{60}Co source. Exposure levels were (from left) 0, 4, 8, 12, 16, 20, 24, 28, 32, 36 kR.

while levels above 20 kR decreased yields (Table 6). Mineral analyses (Table 7) indicated a trend for plants subjected to higher levels of radiation to have more phosphorus and less potassium in shoots than did controls. Most of the micronutrients analyzed tended to increase in shoots of plants which had received higher levels of radiation.

Table 6. Yield of *Y. schidigera* irradiated with different levels of acute gamma radiation from a ^{60}Co source and then grown for 1 year in soil in the glasshouse.

Radiation level (kR)	Root	Top	Total	Top/root ratio
	g dry weight per plant			
0	3.69	5.64	9.33	1.53
4	5.18	8.54	13.72	1.64
8	5.21	8.65	13.86	1.66
12	6.78	7.41	14.19	1.09
16	5.10	5.70	10.80	1.11
20	1.93	5.31	7.24	2.75
24	1.98	3.19	5.17	1.61
28	1.70	2.18	3.88	1.28
32	1.15	2.90	4.05	2.52
36	1.02	0.98	2.00	0.96

Table 7. Mineral composition of shoots of *Y. schidigera* seedlings irradiated with acute doses of gamma radiation from a ^{60}Co source and then grown in Yolo loam soil for 1 year.

Radiation level (kR)	Na	P	K	Ca	Zn	Cu
	% of dry weight				ppm of dry weight	
0	0.10	0.21	2.87	3.14	3	4
4	0.10	0.30	3.51	3.92	5	6
8	0.04	0.21	2.96	2.74	8	4
12	0.04	0.25	3.35	2.01	20	6
16	0.10	0.17	3.62	3.11	10	4
20	0.09	0.29	3.84	2.05	13	7
24	0.10	0.84	2.00	4.40	12	17
28	0.10	0.86	1.98	3.55	21	12
32	0.10	1.00	2.08	2.60	13	25
36	0.12	1.02	1.77	3.35	12	20

	Mn	B	Al	Ti	Fe	Mo	Ni
	ppm of dry weight						
0	85	46	352	22	213	1.0	5
4	87	37	960	80	408	1.3	7
8	132	51	85	3	186	0.5	2
12	256	200	271	12	264	1.6	6
16	226	161	423	20	258	1.2	4
20	257	219	158	6	212	0.7	8
24	172	129	2186	412	784	2.5	13
28	225	146	2112	448	665	2.4	14
32	302	321	1934	570	681	4.0	17
36	124	157	1948	453	694	4.3	16

Summary

Age of Yucca schidigera and Yucca brevifolia can be estimated reasonably well by either counting vascular bundle rings or by counting numbers of blades, or from measuring height. The first method requires sacrificing the plant. On plants sprayed with water-base paint to differentiate between previous and new year's growth, an average of 18 new leaf-blades in 3 sets of 6 normally developed each year for both species. More or less of these sets of leaves may develop in the unusually wet or dry years. There is some evidence that the Y. brevifolia population is advancing down the bajada onto the playa in Yucca Flat. These Yucca plants do not flower each year. Y. brevifolia is more tolerant of salt than is Y. schidigera and it absorbs less sodium—factors which may be involved in the natural distribution of these species. Both species of Yucca seedlings grew best at root temperatures near 18°C and without $CaCO_3$ in the soil. Acute levels of gamma radiation prior to a subsequent year of continued growth in soil resulted in a slight growth stimulation from 4 to 12 kR, followed by a suppression of growth as the dosage levels were increased to 36 kR. Gamma radiation treatments had great influence on the ion transport processes in these plants.

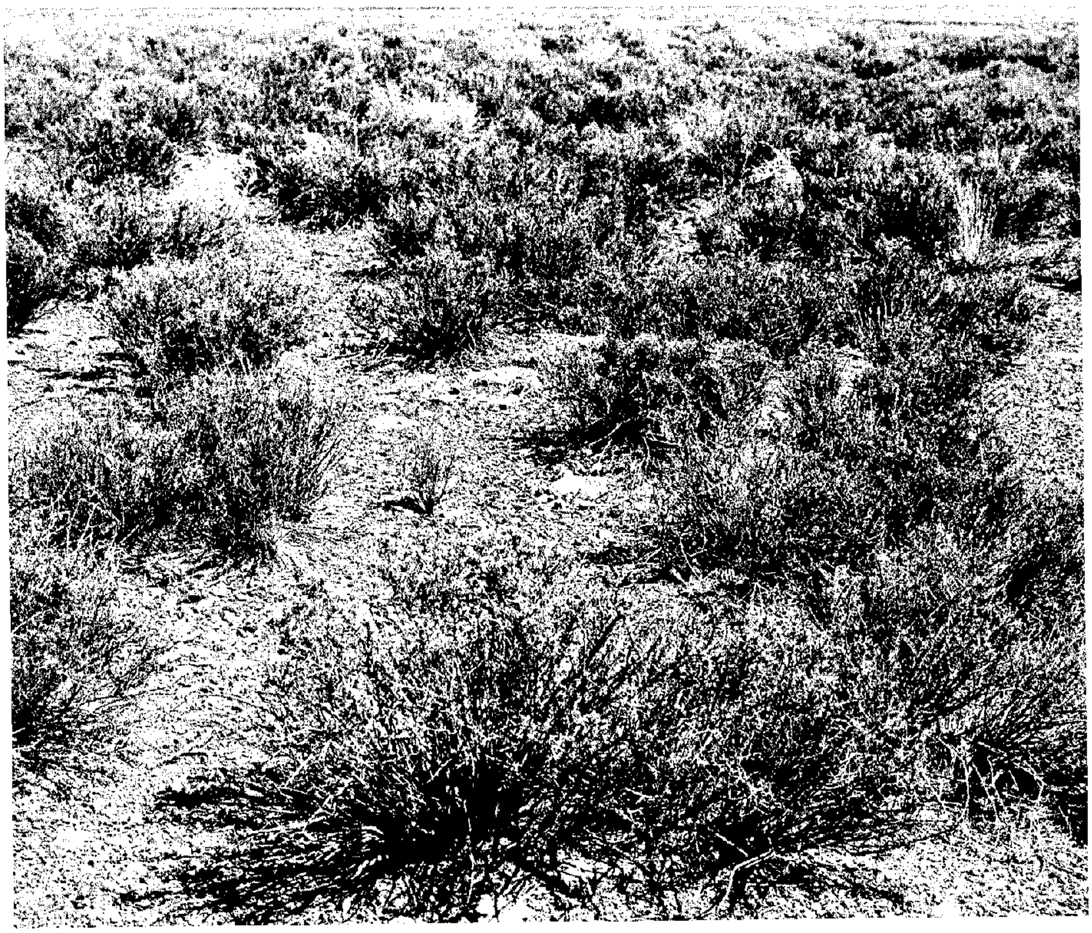
CHARACTERISTICS OF COLEOGYNE RAMOSISSIMA (BLACKBRUSH)

Coleogyne ramosissima Torr. occupies an intermediate spot between the Mojave and Great Basin Desert vegetation at the Nevada Test Site. It is a dominant shrub on upper bajadas of drainage basins at elevations ranging from 900 to 1800 m (Beatley, 1965).

Shreve and Wiggins (1964) give it the following description:

> Coleogyne ramosissima Torr., Pl. Frem. 8 pl. 4, 1854.
>
> Rounded or straggly shrub 0.3 - 2 m high; bark gray, finely striate-fissured; leaves appearing fasciculate but opposite and closely crowded on lateral spurs, linear-oblanceolate, 4 - 11 mm long, obtusish and often mucronulate at apex, plane or nearly so above, 4-grooved beneath, canescent with centrally attached, 2-branched hairs lying horizontal with surface; stipules subtriangular, 1 mm long or less, persistent after leaf blade falls; calyx lobes 6 - 8 mm long, outer pair ovate to

Figure 1. Nearly pure stand of C. ramosissima on the bajada of western Yucca Flat drainage basin.



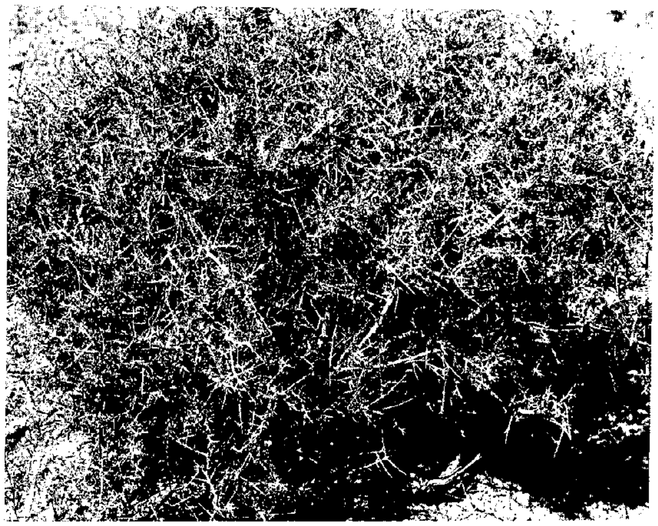


Figure 2. Common shrub form of C. ramosissima growing at the Nevada Test Site.

lanceolate, acute, inner pair ovate to obovate, obtusish or acute, abruptly mucronulate; sheath membranous, about equaling calyx lobe, gradually tapering toward 5-toothed apex, silk-villous within, glabrous without; fruit an ovate, slightly curved, glabrous achene 6 - 8 mm long.

Its distribution according to Benson and Darrow (1954) is on slopes and mesas in the upper creosote-bush desert and the lower sagebrush desert at 920 to 1540 m elevation. It occurs in California, in the Mojave Desert and on the western border of the Salton Sea basin of the Colorado Desert, southern Nevada, Utah, southwestern Colorado, northern Arizona along the Colorado and Little Colorado River drainages and southward in the Mojave Desert in Mohave and Yavapai Counties. Benson and Darrow further note that the dark gray bark of this densely branched shrub turns black when wet, hence the name "Blackbrush." C. ramosissima occurs abundantly in southern Utah and northern Arizona, and it forms pure stands in large areas in the transition region between the creosote-bush and sagebrush deserts. The shrub is eaten particularly by sheep and goats and withstands heavy grazing.

Nearly pure stands of C. ramosissima also occur at the Nevada Test Site (Figure 1), and it is almost always associated with course textured to stony soils. The form of this shrub is normally compact and symmetrical (Figure 2), consisting of a cluster of multi-stem segments which, when pulled apart, are

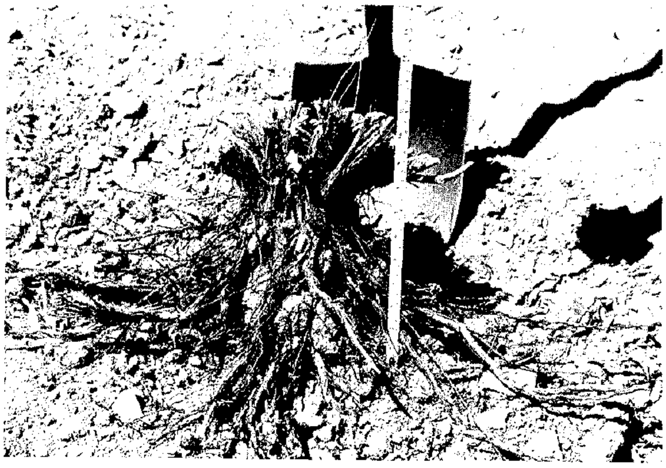


Figure 3. Exposed multi-stem and root system of the shrub in Figure 2.

attached to separate segments of the root system (Figure 3). This stem and root segmentation becomes more pronounced in mature shrubs as illustrated in Figure 4. Another interesting characteristic of this shrub is its ability to survive in very shallow soils over increasingly impervious hard pan formations of the type illustrated in Figure 4. The root system penetrates to the hard pan layer and then spreads in all directions. The chunk of material from the hard pan layer shown in Figure 4 was obtained only after considerable effort with a heavy pick and pry-bar. The area of shallow, hard pan soil examined had less than one half the density of shrubs present on deeper soils nearby, indicating an accomodation of the shrub population to the differences in available moisture.

Like many other species at the Nevada Test Site in the summer of 1967 and 1968 following late July and August rains, the leafless and apparently dormant C. ramosissima shrubs resumed growth with a new flush of leaves indicating that its dormancy is a matter of low soil moisture rather than of high temperatures. It would therefore seem to have no chilling requirement, and this was further indicated by its lack of response to chilling treatments under laboratory conditions. In glasshouse studies we have had rooted cuttings of this species remain evergreen for two successive years when supplied adequate soil moisture. It does not appear to require a dormancy period for continued, healthy growth.

Experimental Results

We have not collected many seeds of C. ramosissima for laboratory studies

Figure 4. Pronounced segmentation of stem and root system of a mature C. ramosissima shrub.

Table 1. Mineral composition of *C. ramosissima* from the Nevada Test Site.

Location	Plant part	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
		% of dry weight						ppm of dry weight											
Red Mountain	Leaf	.10	.03	1.87	1.99	.36	.27	<10	3	316	27	50	336	43	1.8	0.5	0.7	83	25
West Frenchman Flat	Leaf	.21	.04	1.35	2.84	.40	.27	<10	1	280	62	32	644	47	1.2	0.8	1.2	98	24
Mercury Plots	Leaf	.14	.03	1.47	2.71	.36	.24	<10	26	281	55	22	512	16	1.9	T	5.0	77	26
	Stem	.06	.01	0.41	0.64	.13	.13	16	24	137	10	13	204	14	1.0	1.1	18.7	32	16
Yucca Mountain	Leaf	.21	.04	1.54	2.87	37	.18	<10	5	176	112	36	279	12	4.9	1.7	12.0	113	17
	Stem	.16	.04	1.16	1.62	.23	.23	<10	3	334	52	39	418	31	2.3	4.9	9.1	96	24
West Yucca Flat	Leaf	.28	.02	1.81	4.77	.48	.23	54	8	252	31	33	520	9	1.0	2.6	3.7	233	179
	Stem	.20	.01	1.63	1.54	.21	.15	26	7	193	11	34	205	6	T	1.6	1.3	108	142
Mine Mountain Road	Leaf	.07	.01	0.98	3.85	.51	.25	40	4	192	31	38	326	12	6.6	1.5	3.3	190	32
	Stem	.08	.01	1.30	1.59	.24	.13	16	3	193	12	49	227	4	T	T	1.2	102	29

Table 2. Mineral composition of leaves of *C. ramosissima* grown for 60 days in Yolo soil at different soil temperatures.

Temp. °C	Yield g dry wt /plant	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Mo	Co	Ni	Sr	Ba
		% of dry weight						ppm of dry weight											
16	0.90	.29	.50	3.30	3.58	.68	.31	<10	8	350	130	44	762	69	1.8	0.6	3.1	112	96
21	2.13	.28	.54	3.05	3.12	.66	.22	<10	5	345	119	75	521	43	1.3	1.3	4.9	94	127
28	0.66	.26	.32	2.25	3.19	.65	.31	<10	4	444	105	78	758	90	1.2	0.8	4.7	94	180

mainly because this species is one of the most easy to propagate vegetatively. Cuttings from it root readily by putting the stem pieces into soil in a low humidity propagation chamber. Uniform cuttings have been obtained easily for soil pot culture and hydroponic culture experiments. One disadvantage has been that this species is the most susceptible to white fly infestation of all the desert shrub species we have studied.

C. ramosissima is one of the species for which the acetylene reduction test indicates nitrogen fixation in roots. This species is a member of the family Rosaceae. Presumably this nitrogen fixation system is symbiotic since this kind of process has been identified in three other members of the rose family, Purshia (Wagle and Vlamis, 1961; Webster et al., 1967), Dryas (Lawrence et al., 1967) and Cercocarpus (Vlamis et al., 1964). The endophyte involved has proved to be actinomycetes. Actinomycetal symbiosis also may occur with C. ramosissima; however, this is purely speculative since we have made no attempts as yet to identify the system present and have only detected that nitrogen fixation does occur in roots of this species.

C. ramosissima is moderately sensitive to gamma radiation. The LD_{100} from acute doses of ^{60}Co irradiation ranges from 6 to 10 kR; its susceptibility is greater when in the more succulent state of growth.

Soil pot and hydroponic culture experiments show rooted cuttings of this species to be moderately tolerant of salinity but we do not see evidence to support this in the field. On the contrary, C. ramosissima is found only on non-saline soils, usually of calcareous nature. The sensitivity of seeds to salinity may be a limiting factor governing field distribution of this species.

The mineral composition in samples of C. ramosissima from the field is shown in Table 1. Leaves are low in sodium and moderately high in calcium. Leaf tissues normally contain about 2 per cent total nitrogen.

An experiment with rooted cuttings grown in Yolo loam at different root temperatures showed that C. ramosissima grew better at 21°C than at 16 or 28°C (Table 2, Figure 5). This indicates that it is an intermediate temperature zone plant just as it is found in the field. The leaves were high in calcium but little related to soil temperature. Also these leaves from plants grown on Yolo soil contained more sodium than did those grown in the field; of interest is the high aluminum content of leaves of plants grown in the field and in the glasshouse.

Seeds of C. ramosissima did not germinate when planted in vermiculite and placed in the glasshouse with day temperatures between 25 and 30°C. The flat containing both seed and vermiculite with moisture was placed in a refrigerator at 5°C for 2 weeks before germination occurred. We routinely germinate seed of this species now by placing them in the refrigerator after planting them in vermiculite with moisture.

Summary

Coleogyne ramosissima occupies an intermediate zone between the Great Basin and Mojave Desert vegetation. It occurs in mixed or in pure stands and is associated with course textured to stony soils of calcareous nature. Nitrogen fixation occurs in the root system of this shrub. Leaf tissues normally contain about 2% total nitrogen. Vegetative propagation by rooted cuttings is easy to accomplish with this species. Its growth is related to soil temperature and appears to be optimal at about 21°C. Seeds of this species did not germinate in the glasshouse but did in vermiculite in a refrigerator at 5°C after two weeks exposure. Rooted cuttings of this species are fairly resistant to salini-

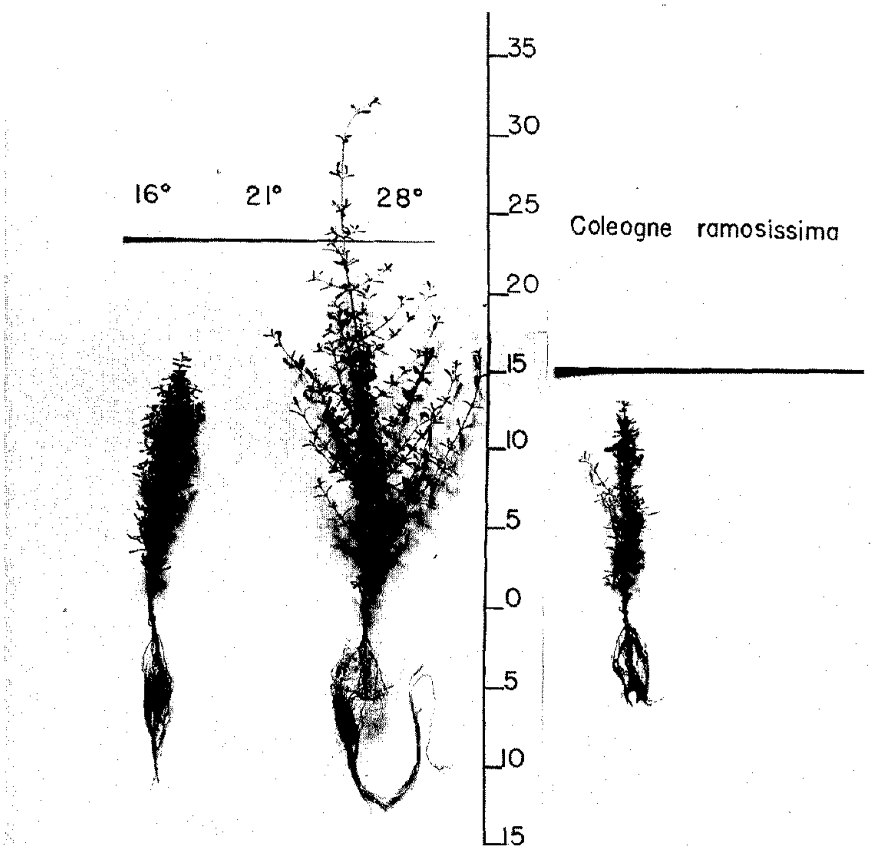


Figure 5. C. ramosissima grew best at 21°C root temperature in Yolo loam soil.

ty, but this is not evident in the field; sensitivity of seed to salinity may govern field distribution. While normally high in calcium and low in sodium when grown in the field, leaf tissues will accommodate moderate amounts of sodium when rooted cuttings are grown in soil where more sodium is available. Leaves were high in content of aluminum.

A STUDY OF A MEASURE OF SPECIES ASSOCIATION BETWEEN PAIRS OF PERENNIAL PLANTS IN DESERT HARDPAN SOIL

This report discusses one of several phases of a research program at the Nevada Test Site which is designed to investigate the ecological and physiological characteristics of perennial plant species native to the northern Mojave Desert. A series of environmental study plots have been established to investigate the effects of irrigation, fertilizer amendments, and herbicides on primary productivity and radionuclide cycling of these perennial plants. Included in this program are studies of the spatial relationships among the plants in desert hardpan soil.

Spatial relationships among and within natural plant species commonly are examined and characterized in terms of association, dispersion, patterning, trend, etc. Early work in these areas of interest has been reviewed by Goodall (1952), Hanson (1958), Cain and Castro (1959) Whittaker (1962), and McIntosh (1967). In recent reviews, Langford and Buell (1969) emphasized the concepts of integration, identity, and stability in plant association, and Goodall (1970) discussed the underlying principles and probable course of development of statistical plant ecology. Among the well-known examples of efforts to bring quantification into studies of natural vegetation are the works of Grieg-Smith (1964), Kershaw (1964), and Lambert and Dale (1964). Pielou (1969) provided a particularly penetrating review of the mathematical and statistical methods employed in these studies. One of her statements, in essence, sets the theme for this work: ". . . If two co-occurring species are affected by the same environmental factors, or if they have some effect, either favorable or unfavorable, on each other, their patterns will not be independent; the species will be associated, either positively or negatively. Association or the lack of it among pairs and groups of species is therefore of obvious ecological interest . . . " (ibid. p. 159).

It is the purpose of this present report to describe a method of measuring association which seems appropriate to the study of plants in Mercury Valley. It is felt that this measure of association, which is based on a probabilistic model, will indicate the strength of association (or counterassociation) between species pairs. The quantitative evaluation of this measure of association tends to support the investigators' subjective observations concerning the various species pairs. Application of the method to other ecological associations is straightforward, and its use should aid in clarifying many phenomena.

Field Methods

The site of the study area is Mercury, Nevada, near the waste water ponds from the local sewage processing system. Close proximity to a source of irrigation water was one prerequisite for the overall research program. The soil at this site is underlain by a virtually impervious hardpan layer at depths varying from 15 to 75 cm. The thickness of the hardpan layer is usually greater than 10 cm.

Perennial plants grow both singly and in clumps, separated by bare areas of desert soil (Figure 1). The size and spacing of the clumps is irregular. As many as 10 different species may grow together in a single clump (Figure 2). For this study, the concept of a vegetational unit was devised. A vegetational unit is either a single plant or a clump of plants. Clump membership is determined by field observation; a plant is declared a member of a clump if its foliage touches or overlaps (as viewed from above) the foliage of at least one other member of the clump. Thus, the vegetational unit is analogous to that of a family unit in a human population census being either a single person or a group of related persons.

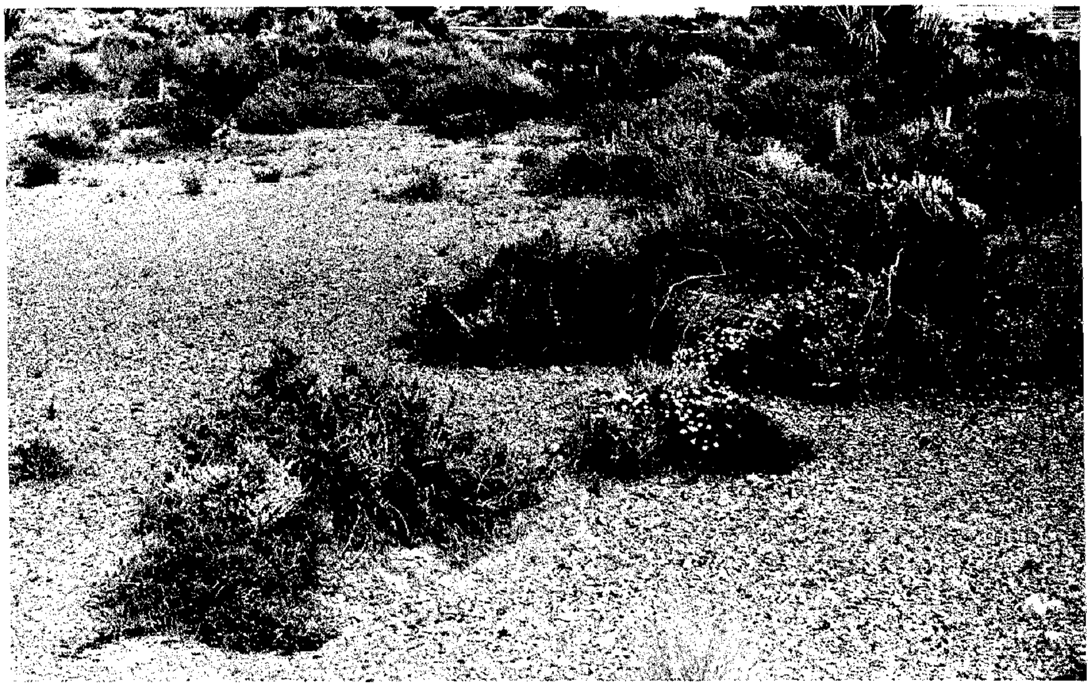


Figure 1. Vegetation of desert hardpan soil. Shrubs tend to clump together separated by bare areas of desert pavement.

A census was made in the summer of 1968 of all perennial plants (including shrubs, grasses, herbs, and their seedlings) in 25 circular experimental plots, each plot being 30.5 m in diameter. Each plant was categorized as to its species and its vegetational unit membership. This census effort involved more than 19,000 individual plants representing 28 different species.

A special method was devised for the purpose of locating and cataloging each plant in each plot. A permanent standpipe for mounting a surveyor's transit was installed at the center of each plot, with a marker located on magnetic north at a distance of 15.25 m. Orientation for each vegetational unit was the measured distance from the plot center to the vegetational unit center. The azimuth for each unit was measured from magnetic north (0°) to the center of the vegetational unit. The unit's greatest and smallest width and its species content were recorded. Each species within a unit was measured in like manner, and it was further identified by height (Figure 3). These data were recorded and transferred to punch cards for computer processing.

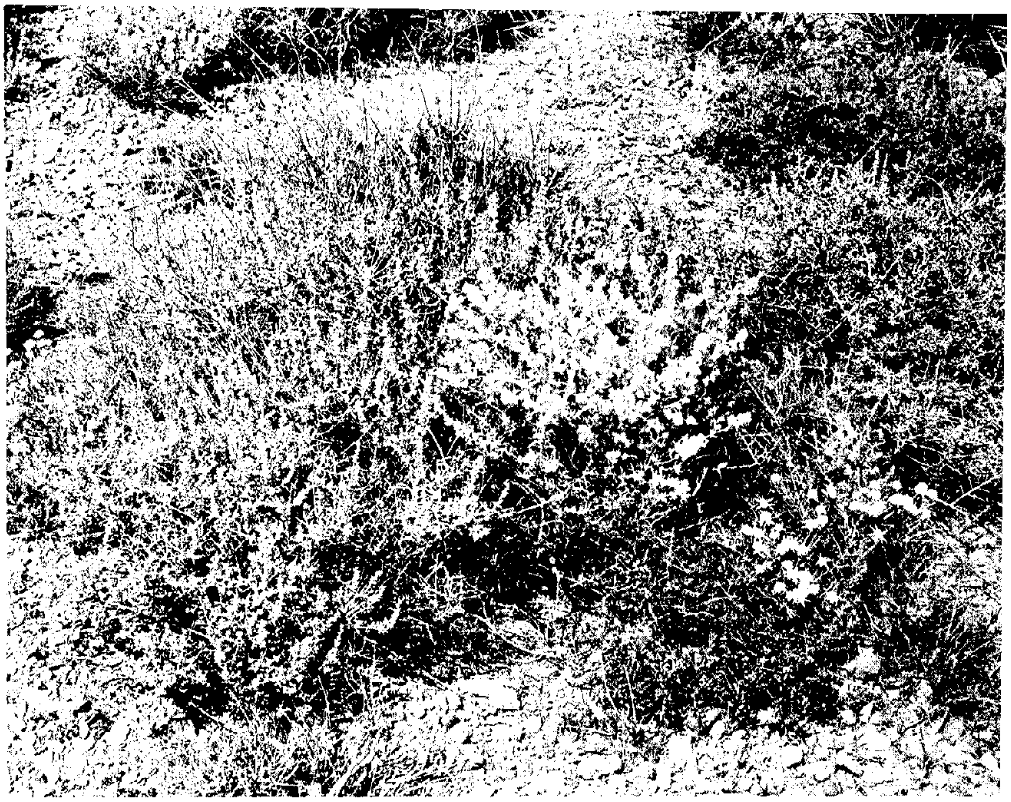
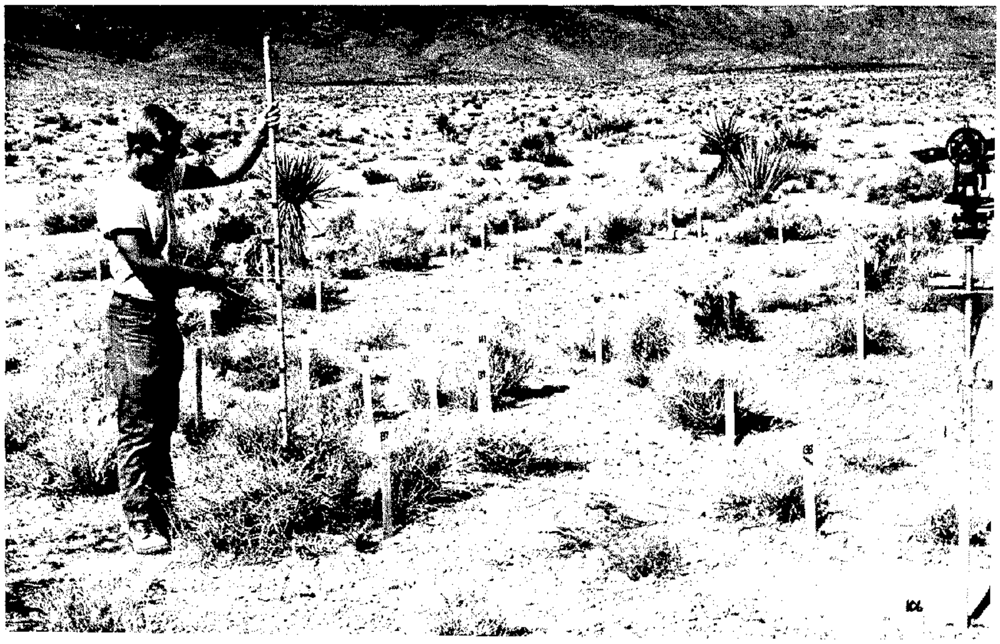


Figure 2. Typical clump of shrubs in group association. Present are *Acamptopappus shockleyi*, *Eurotia lanata*, *Lycium andersonii*, *Ephedra nevadensis*, *Franseria dumosa*, *Krameria parvifolia* and several different winter annual species.

Figure 3. In the plot census each shrub is identified by polar coordinates and its status within or without a clump.



Statistical Considerations

The data collected in the census can be treated in several ways. For instance, having chosen a pair of species, say A and B, each vegetational unit can be counted as having both species absent, A present and B absent, A absent and B present, or both A and B present. This leads to the conventional 2 × 2 table:

		Species B		
		Absent	Present	
Species	Absent	a	b	$m = a + b$
A	Present	c	d	$n = c + d$
		$r = a + c$	$s = b + d$	$N = m + n = r + s.$

Methods of analysis of such tables and a stern lecture against their misuse are given by Pielou (1969, Chapter 13).

Because the collected data in this study go far beyond indicating mere absence or presence of a species in a vegetational unit, a more indicative procedure was sought. Having chosen a species pair, A and B, the actual numbers of each species in each vegetational unit were available to form a two-dimensional "scattergram." Thus, it was possible to form an R×S table, whose entries were the number of vegetational units containing exactly r plants of species A and s plants of species B, where r can take the values 0, 1, ..., R and s can take the values 0, 1, ..., S:

		Number of plants of species B						
		0	1	2	...	s	...	S
Number	0	n_{00}	n_{01}	n_{02}	...	n_{0s}	...	n_{0S}
of	1	n_{10}	n_{11}	n_{12}	...	n_{1s}	...	n_{1S}
plants	2	n_{20}	n_{21}	n_{22}	...	n_{2s}	...	n_{2S}
of	.	.	.	.		.		.
	.	.	.	.		.		.
species	.	.	.	.		.		.
A	r	n_{r0}	n_{r1}	n_{r2}	...	n_{rs}	...	n_{rS}
	.	.	.	.		.		.
	.	.	.	.		.		.
	.	.	.	.		.		.
	R	n_{R0}	n_{R1}	n_{R2}	...	n_{Rs}	...	n_{RS}.

In this table n_{rs} is the number of vegetational units containing r plants of species A and s plants of species B. This sort of table is a representation of a discrete bivariate situation, and it suggests the use of a correlation coefficient as a measure of association. However, correlation coefficients are based upon the assumption of a linear relationship between the two random variables, and data collected from the survey tended to generally show an "Lshaped" behavior, with most of the non-zero frequencies occurring in the upper rows and left-side columns, thus showing a pronounced nonlinear connection between the two variables. Moreover, the statistical characteristics (sampling distribution, expected value, variance, etc.) of the correlation coefficient are little known except for the case of bivariate normality, and it is manifest that the discreteness of these tables precludes the assumption of normality.

It was finally decided to use a measure of association for two discrete, but ordered, polytomies that was promulgated by Goodman and Kruskal (1954, 1963). Several reasons guided this choice: the measure can be defined to characterize statistical populations and samples from those populations, it was developed for the two-way tables for which both classifications have "intrinsic and relevant order," as specified by Goodman and Kruskal (1963, p. 322), and the large-sample statistical characteristics of estimates of the measure are known.

When the Goodman-Kruskal procedure is applied to an entire population with respect to two ordered variables, the measure is denoted by γ. When the procedure is applied to a random sample from the population of interest, the measure is denoted by G. The distinction between the symbols γ and G and their meanings is important in many applications of this measure of association. For example, the difference $(G - \gamma)$ has been shown to be normally distributed with a particular variance for large sample sizes. This fact permits the testing of statistical hypotheses about an especially interesting value of γ or with respect to the comparability of several G's from different populations.

As part of the effort to understand the Goodman-Kruskal procedure as it applies to the present study, the data collected during the 1968 census were treated both as deriving from a full population and from a number of sampling experiments in which the vegetational units were considered the sampling units. Regardless of the assumption of a full population study or a sampling study, there are at least two ways to amalgamate the data from the 25 plots into a single summary figure: (1) a single two-way table can be created for the entire set of data for a particular species pair, yielding a "total" or "overall" measure of association; or (2) the measures from the individual plots can be averaged, yielding a "pooled" measure of association. Both methods were applied to these data.

Details of the theory and computation of the Goodman-Kruskal (herein after designed by G-K) measure of association appear in Addendum A. However, some indication of its derivation and interpretation is in order. The terminology and notation is that used by Goodman and Kruskal (1954, 1963) in their development. Modifications applicable to the present perennial plant study are indicated where necessary.

A double polytomy for a population can be represented in a two-way table (see Table 1) where

classification A divides the population into α classes $A_1, A_2, \ldots, A_\alpha$;

classification B divides the population into β classes $B_1, B_2, \ldots, B_\beta$;

and the proportion of the population that is classified as both A_α and B_β is $\rho_{\alpha\beta}$. The marginal proportions are denoted by $\rho_{\alpha .}$ (the proportion of the population classified as A_a) and $\rho_{. \beta}$ (the proportion of the population classified as B_b). The sum of the marginal proportions, either by rows or columns, equals unity, as does the sum of the two-way proportions by rows and columns, because each member of the population <u>must</u> be classified into one of the cells of the double polytomy.

Table 1. A double polytomy for a population.

A			B		
	B_1	B_2	$\cdots$	B_β	Total
A_1	ρ_{11}	ρ_{12}	$\cdots$	$\rho_{1\beta}$	$\rho_{1\cdot}$
A_2	ρ_{21}	ρ_{22}	$\cdots$	$\rho_{2\beta}$	$\rho_{2\cdot}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
A_α	$\rho_{\alpha 1}$	$\rho_{\alpha 2}$	$\cdots$	$\rho_{\alpha\beta}$	$\rho_{\alpha\cdot}$
Total	$\rho_{\cdot 1}$	$\rho_{\cdot 2}$	$\cdots$	$\rho_{\cdot\beta}$	1

The G-K measure of association (γ) is based on three additional criteria:

(i) There are no relevant underlying continua for the polytomies.
(ii) Directed ordering is of interest.
(iii) The two polytomies appear symmetrically.

By (ii) Goodman and Kruskal mean to distinguish between, in the 3 × 3 case, for example,

$$\begin{array}{ccc} \rho_{11} & 0 & 0 \\ 0 & \rho_{22} & 0 \\ 0 & 0 & \rho_{33} \end{array} \qquad \text{and} \qquad \begin{array}{ccc} 0 & 0 & \rho_{13} \\ 0 & \rho_{22} & 0 \\ \rho_{31} & 0 & 0 \end{array}$$

calling the first of these "complete association" and the second "complete counter association." A useful convention to adopt is that in these two cases the measure γ should take the values +1 and -1, respectively.

Goodman and Kruskal point out that there are vaguenesses in the idea of complete ordered association. For example, everyone would probably agree that the following case is one of complete association, even though there are zeroes on the main diagonal:

$$\begin{array}{ccc} 0 & 0 & 0 \\ \rho_{21} & 0 & 0 \\ 0 & \rho_{32} & 0 \end{array}$$

The following situation is not so clear:

$$\begin{array}{ccc} \rho_{11} & 0 & 0 \\ \rho_{21} & \rho_{22} & 0 \\ 0 & \rho_{32} & \rho_{33} \end{array}$$

Goodman and Kruskal (1954, p. 748) comment: ". . . the procedure we shall adopt toward this and more complex questions is to base the measure of association on a probabilistic model of activity which often may be appropriate and typical."

The G-K γ is based on these considerations. Suppose that two individuals are selected independently and at random from the population (technically with replacement, but this is unimportant for large populations). Each individual is categorized into some (A_a, B_b) cell in the two-way table. Suppose the first falls into the $A_{\underline{a}_1}, B_{\underline{b}_1})$ cell and the second into the $(A_{\underline{a}_2}, B_{\underline{b}_2})$ cell. The underlined letters denote random variables because the cell for the individual is not determined until the individual is observed; thus $\underline{a}_i$ $(i = 1, 2)$ takes values from 1 to α and $\underline{b}_i$ $(i = 1, 2)$ takes values from 1 to β.

If the two polytomies are independent in a statistical sense (i.e., $\rho_{ab} = \rho_{a \cdot} \rho_{\cdot b}$ for $a = 1, \ldots, \alpha$ and $b = 1, \ldots, \beta$), it is to be expected that the order of the $\underline{a}$'s has no connection with the order of the $\underline{b}$'s. If there is association, it is to be expected that the order of the $\underline{a}$'s would generally be the same as the order of the $\underline{b}$'s (i.e., if $\underline{a}_1$ is greater than $\underline{a}_2$, it would be expected that $\underline{b}_1$ be greater than $\underline{b}_2$, and conversely). If there is counter association, it is to be expected that the order of the $\underline{a}$'s would generally be reversed from the order of the $\underline{b}$'s (i.e., if $\underline{a}_1$ is greater than $\underline{a}_2$, it would be expected that $\underline{b}_1$ be less than $\underline{b}_2$, and conversely).

The measure γ is based on the difference between the probabilities of like (same) orders and unlike (different) orders. Ambiguity is avoided by taking these probabilities conditionally on the absence of ties (i.e., a tie is declared if either $\underline{a}_1 = \underline{a}_2$ or $\underline{b}_1 = \underline{b}_2$).

Let
π_s = probability that both pairs of orders are the same,
π_d = probability that one pair of orders is different from the other,
and π_t = probability of a tie in at least one of the orders.
Then the G-K measure of association is defined by the formula

$$\gamma = \frac{\pi_s - \pi_d}{1 - \pi_t} .$$

Thus, γ is the difference between the conditional probabilities of like and unlike orders, given no ties. In other words, γ indicates how much more probable it is to get like than unlike orders in the two classifications when two individuals are chosen at random from the population and ties are ignored.

Several properties of γ are worth noting:

(i) γ is not defined if the population is concentrated in a single row or column of the two-way table, for then the probability of a tie is certain and $\pi_t = 1$ implies the denominator of γ is zero.

(ii) γ is +1 if the population is concentrated on any upper-left to lower-right diagonal of the two-way table, and γ is -1 if the population is concentrated on any lower-left to upper-right diagonal.

(iii) Any number of rows or columns, all of whose ρ's are zero, can be added to or inserted in the two-way table without changing the value of γ.

(iv) If the two polytomies are independent, then $\gamma = 0$. But the converse need not hold except for the 2 x 2 case. As an example of nonindependence with $\gamma = 0$, consider the table which follows.

$$\begin{matrix} .2 & 0 & .2 \\ 0 & .2 & 0 \\ .2 & 0 & .2 \end{matrix}$$

(v) $\gamma = +1$ if the population is concentrated either on the first row and last column or on the first column and last row. $\gamma = -1$ if the population is concentrated either on the first row and first column or on the last row and last column. Goodman and Kruskal (1954, p. 750) imply they would call these cases of "complete curvilinear association" and "complete curvilinear counter association," respectively.

(vi) The number of rows need not equal the number of columns, so that the table need not be square (even though it will be square in many applications).

(vii) In the 2 x 2 case ($\alpha = \beta = 2$), it can be shown that γ is identical with the measure Q, developed by Yule (1912). Moreover, in this case, γ is either +1 or -1 if a single cell is empty.

Most of the immediately foregoing material has concentrated on the idea of a population and the development of a measure of association between two polytomies within each of which every population member can be classified. What of the problem of dealing with a sample from the population? It is to this question that Goodman and Kruskal (1963) provide answers which can be employed in this perennial plant study.

A sample of size n is drawn from the population. The A and B classifications of each member of the sample are observed. Let N_{ab} be the number of individuals in the sample that fall into the (A_a, B_b) cell; that is, N_{ab} is the number of sample individuals having A classification A_a and B classification B_b. It follows that

$$\sum_{a=1}^{\alpha} \sum_{b=1}^{\beta} N_{ab} = n$$

because each sample individual must be classified into one of the $\alpha\beta$ cells in the $\alpha \times \beta$ table. The notation R_{ab} (corresponding to ρ_{ab}) is used for the proportion, N_{ab}/n, of the sample in the (A_a, B_b) cell; $R_{a.}$ for $N_{a.}/n = \sum_b R_{ab}$ (when the row totals are not fixed before sampling); and so on. Finally, $\sum_a \sum_b R_{ab} = 1$. Computational details are left for Addendum A.

One point bears repeating: When the entire population of vegetational units is considered, then the G-K measure of association is a population-related measure and is denoted γ, and no statistical sampling theory need be nor should be constructed for such a situation. On the other hand, when a sample of vegetational units is being considered, then the sample-related measure of association is an estimate of γ and is denoted G, and it is imperative that the sampling characteristics of G be understood. Thus, it is that the "variance of G" is important. If σ_G^2 is the notation for the variance of G, then it must be appreciated that σ_G^2 is the variance of the sampling distribution of G; i.e., σ_G^2 is the variance of G that will apply to the distribution of all the estimates of G if the experiment were conducted many times with the same sample size and sample population value γ. It turns out that σ_G^2 is a function of the "true" values of the cell frequencies, the ρ_{ab}'s, and therefore an estimate of the variance of G must be derived from the sample in practical situations. This requirement has been satisfied by Goodman and Kruskal (1963). This estimate is denoted by s_G^2. Further discussion is given in Addendum A.

Another statistical procedure used in dealing with these data involves the comparison of several values of G with each other. Suppose that I samples of vegetational units have been examined, and suppose that a value of G has been determined for each sample; thus, there is a set, denoted $G_1, \ldots, G_i, \ldots, G_I$, of G's, and associated with each member of the set there is a corresponding variance. It may be of interest to determine whether the I values of G could have come from a single population. As shown in Addendum B, a reasonable test statistic can be developed, based upon the Chi-squared distribution, which provides a statistical answer to the question. Briefly, the test procedure requires the computation of a pooled average value, denoted $\bar{G}$, and the comparison of each G_i (in terms of its own standard deviation) with $\bar{G}$. The assumption (hypothesis) of a common value of γ is supported (accepted) if the test statistic is small; it is repudiated (rejected) if the test statistic is large. As a side feature of this test, it is possible to look at each G_i and determine its contribution to the support or repudiation of the assumption of a common γ.

Computer Implementation

Once the 1968 census data were available on punched cards, it was necessary to prepare computer programs to process them along the lines mentioned on page 208. The several resulting programs were written in the PL/1 language and processed on UCLA's IBM 360/91. The programs were designed to provide the following kinds of output:

(i) A 20 × 20 two-way table was prepared for every species pair for every experimental plot.

(ii) The G-K measure of association was prepared for each of the tables, along with appropriate intermediate values and standard deviation.

(iii) The data for all plots were combined into individual two-way tables with associated computations.

(iv) The measures of association were compared across the experimental plots for each pair of species and the appropriate statistic was perpared for testing the hypothesis of identical γ's.

As an example of (iii), see Table 2. Computed values of G and its "standard deviation" are shown in Table 3. Table 4 shows a typical print-out for (iv) in which all values of G are positive, while Table 5 shows a similar print-out for which the values of G are predominately negative.

A preliminary examination of the census data showed that not more than 19 individuals of a particular species appeared in an individual vegetational unit. However, the full 20 x 20 two-way tables were employed because the computed measure of association cannot be affected by additional rows and columns of zeros.

```
                    SPEC-11      EUROTIA LANATA      IS COMPARED TO SPEC-17     LYCIUM ANDERSONII

                            SPEC-17     LYCIUM ANDERSONII            NO. OF PLANTS IN CLUMP               SP 11  FREQ DIST
                              0    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18    19
                          *******************************************************************************************************
                         0 5268  273   46    3    2    0    0    0    0    0    0    0    0    0    0    0    0    0    0  5592
                          *******************************************************************************************************
                         1 1021  130   21    6    3    0    0    0    0    0    0    0    0    0    0    0    0    0    0  1181
                          *******************************************************************************************************
                         2  218   94   14    5    2    0    0    0    0    0    0    0    0    0    0    0    0    0    0   333
                          *******************************************************************************************************
                         3  110   45   13    3    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0   172
                          *******************************************************************************************************
                         4   42   38   12    2    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    94
                          *******************************************************************************************************
                         5   33   39    7    3    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    83
                          *******************************************************************************************************
                         6   16   15    6    1    3    0    0    1    0    0    0    0    0    0    0    0    0    0    0    42
                          *******************************************************************************************************
                         7    5   12    5    3    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    26
                          *******************************************************************************************************
                         8    4   11    3    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    18
SPEC-11  EUROTIA LANATA   *******************************************************************************************************
                         9    5    7    1    0    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    14
                          *******************************************************************************************************
                        10    0    5    2    0    2    0    0    0    0    0    0    0    0    0    0    0    0    0    0     9
                          *******************************************************************************************************
                        11    1    4    3    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     9
                          *******************************************************************************************************
                        12    0    1    0    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     2
                          *******************************************************************************************************
                        13    0    2    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     2
                          *******************************************************************************************************
                        14    0    1    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     2
                          *******************************************************************************************************
                        15    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
                          *******************************************************************************************************
                        16    0    0    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     1
                          *******************************************************************************************************
                        17    0    2    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     2
                          *******************************************************************************************************
                        18    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     0
                          *******************************************************************************************************
       SP 17 FREQ DIST  19 6724  679  135   28   16    0    0    1    0    0    0    0    0    0    0    0    0    0    0  7582
                          *******************************************************************************************************

                                                              XPS EQUALS        6714691
                                                              XPD EQUALS        1236269
                                                              XPSS EQUALS 23333867202
                                                              XPDD EQUALS  1075590205
                                                              XPSD EQUALS  1224502273
                                                              G EQUALS             0.68903

                                                              STANDARD DEVIATION OF G =               0.01599
```

Table 2. An example of a 20 x 20 two-way table used in this study. A similar table is constructed for each possible species pair combination, either on a separate or on a combined plot basis.

Table 3. Measure of association (G) and estimated standard deviations (s_G) for some prominent species pairs in the combined plots. By design, $-1 \leq G \leq +1$.

Plant species	G	s_G	G	s_G	G	s_G	G	s_G	G	s_G	G	s_G
	A. shockleyi		*E. funerea*		*E. nevadensis*		*E. lanata*		*F. dumosa*		*G. spinosa*	
Acamptopappus shockleyi	-	-	0.127	0.063	0.048	0.063	-0.303	0.024	-0.262	0.022	-0.137	0.056
Ephedra funerea	0.127	0.063	-	-	-0.043	0.181	0.366	0.049	0.437	0.044	0.266	0.109
Ephedra nevadensis	0.048	0.063	-0.043	0.181	-	-	0.216	0.056	0.365	0.089	0.365	0.089
Eurotia lanata	-0.303	0.024	0.362	0.049	0.216	0.056	-	-	0.292	0.019	0.457	0.035
Franseria dumosa	-0.262	0.022	0.437	0.044	0.403	0.045	0.292	0.019	-	-	0.344	0.040
Grayia spinosa	-0.137	0.056	0.266	0.109	0.365	0.089	0.457	0.035	0.344	0.040	-	-
Krameria parvifolia	-0.297	0.029	0.347	0.059	0.277	0.061	0.344	0.023	0.319	0.023	0.535	0.035
Larrea divaricata	-0.381	0.039	0.202	0.081	0.202	0.078	0.461	0.023	0.105	0.032	0.668	0.028
Lycium andersonii	-0.097	0.037	0.552	0.046	0.452	0.055	0.689	0.016	0.457	0.024	0.710	0.025
Machaeranthera tortifolia	-0.091	0.083	0.519	0.100	0.518	0.096	-0.005	0.084	0.434	0.052	0.067	0.169
Sphaeralcea ambigua	-0.187	0.033	0.431	0.055	0.248	0.068	-0.028	0.033	0.089	0.030	0.120	0.066
Yucca schidigera	0.204	0.074	0.562	0.089	0.414	0.120	0.386	0.058	0.459	0.052	0.357	0.114
	K. parvifolia		*L. divaricata*		*L. andersonii*		*M. tortifolia*		S. *ambigua*		*Y. schidigera*	
Acamptopappus shockleyi	-0.297	0.029	-0.381	0.039	-0.097	0.037	-0.901	0.083	-0.187	0.033	0.204	0.074
Ephedra funerea	0.347	0.059	0.202	0.081	0.552	0.046	0.519	0.100	0.431	0.055	0.562	0.089
Ephedra nevadensis	0.277	0.061	0.202	0.078	0.452	0.055	0.518	0.096	0.248	0.068	0.414	0.120
Eurotia lanata	0.344	0.023	0.461	0.023	0.689	0.016	-0.005	0.084	-0.028	0.033	0.386	0.058
Franseria dumosa	0.319	0.023	0.105	0.032	0.457	0.024	0.434	0.052	0.089	0.030	0.459	0.052
Grayia spinosa	0.535	0.035	0.668	0.028	0.710	0.025	0.067	0.169	0.120	0.066	0.357	0.114
Krameria parvifolia	-	-	0.203	0.038	0.641	0.020	0.140	0.088	-0.060	0.040	0.096	0.091
Larrea divaricata	0.203	0.038	-	-	0.502	0.030	0.118	0.107	-0.038	0.049	0.328	0.084
Lycium andersonii	0.641	0.020	0.502	0.030	-	-	0.484	0.064	0.151	0.043	0.613	0.047
Machaeranthera tortifolia	0.140	0.088	0.118	0.107	0.484	0.064	-	-	0.232	0.088	0.423	0.150
Sphaeralcea ambigua	-0.060	0.040	-0.038	0.049	0.151	0.043	0.232	0.088	-	-	0.391	0.072
Yucca schidigera	0.096	0.091	0.328	0.084	0.613	0.047	0.423	0.150	0.391	0.072	-	-

Table 4. Details of testing the hypothesis that each plot has the same value of γ for *Eurotia lanata* and *Krameria parvifolia*. Note that value of G is positive for all 25 plots.

Plot no.	G estimate	Standard deviation	Values for chi square summation
1	0.921	0.069	12.614
2	0.756	0.100	0.641
3	0.570	0.106	0.999
4	0.524	0.089	2.914
5	0.484	0.146	1.728
6	0.559	0.079	2.191
7	0.602	0.082	0.813
8	0.607	0.109	0.400
9	0.463	0.144	2.187
10	0.326	0.208	2.830
11	0.848	0.042	16.783
12	0.576	0.101	0.970
13	0.747	0.064	1.233
14	0.494	0.066	7.599
15	0.579	0.077	1.585
16	0.707	0.060	0.268
17	0.509	0.095	3.088
18	0.694	0.111	0.026
19	0.671	0.092	0.003
20	0.571	0.121	0.752
21	0.550	0.162	0.604
22	0.861	0.096	3.716
23	0.289	0.234	2.734
24	0.612	0.114	0.315
25	0.666	0.069	0.021

Chi square for this species pair is equal to 67.024.
Degrees of freedom equal 24.
$\bar{G}$ equals 0.676.

Table 5. Details of testing the hypothesis that each plot has the same value of γ for Acamptopappus shockleyi and Franseria dumosa. Note that G is negative except for the 5th plot.

Plot no.	G estimate	Standard deviation	Values for chi square summation
1	-0.380	0.098	1.338
2	-0.519	0.086	8.610
3	-0.087	0.092	3.813
4	-0.038	0.102	5.025
5	0.026	0.137	4.563
6	-0.089	0.128	1.926
7	-0.074	0.121	2.535
8	-0.037	0.156	2.167
9	-0.059	0.214	0.942
10	-0.617	0.140	6.263
11	-0.152	0.106	1.170
12	-0.171	0.095	1.014
13	-0.383	0.108	1.161
14	-0.194	0.147	0.244
15	-0.141	0.115	1.194
16	-0.007	0.103	6.355
17	-0.544	0.113	6.024
18	-0.573	0.075	16.685
19	-0.273	0.096	0.004
20	-0.214	0.106	0.247
21	-0.409	0.089	2.558
22	-0.128	0.122	1.292
23	-0.615	0.189	3.397
24	-0.418	0.165	0.841
25	-0.061	0.117	3.089

Chi square for this species pair is equal to 82.456.
Degrees of freedom equal 24.
$\overline{G}$ equals -0.267.

Various additional outputs are prepared by the programs designed for dealing with these data. For example, schematic outputs are prepared which show the location of each plant of a given species within a given plot. The location of all plant species within each plot are similarly displayed. Examples of this type of output are shown in Figures 4A and 4B. This kind of information is useful in the continuing studies of dispersion and patterning in desert vegetation.

Results and Discussion

Space does not permit the display of all species pairs for all 25 experimental plots, for this would require $25 \times (28 \times 27/2) = 9,450$ print-out sheets similar to that shown in Table 2. In general, a great many more positive than negative measures of associations were determined.

If it is assumed that all 25 plots are parts of the same population, then it is reasonable to collect all the data for each species pair into a single two-way table, an example of which is given as Table 2 for *Eurotia lanata* and *Lycium andersonii*. The G-K measure of association has a value of 0.689, indicating positive association. If the entire set of 7,582 vegetational units are considered as a sample of all vegetational units in the Mercury Valley desert community, then the proper summary for these two species states that $G = 0.689$ with $s_G = 0.016$.

Based on the sampling assumption for Table 2, the statistical hypothesis that γ is zero can be tested. Formally, the null hypothesis is $H_0: \gamma = 0$. The test statistic is $z = G/s_G = 0.689/0.016 = 43.1$. This greatly exceeds the conventially used critical values of ± 1.96 (since G is normally distributed), and the null hypothesis is rejected. The constants ± 1.96 arise from testing the hypothesis at the 5 per cent level of significance. If an interval statement about the G-K measure γ is desired, an approximate 95 per cent confidence interval's endpoints can be constructed from $G \pm 1.96 s_G = 0.689 \pm (1.96 \times 0.016)$ which yields 0.658 and 0.720 as the endpoints. Addendum B contains a discussion of confidence interval construction.

The probabilistic interpretation of either the hypothesis test or the confidence interval is: Barring ties, there is a greater chance of like order than of unlike order with respect to the numbers of plants of the two species in a random selection of two vegetational units.

In Table 3 will be found a listing of G and s_G for the combined data involving some of the more prominent species found in the 1968 census.

Tables 4 and 5 display examples of the printout for the test of the hypothesis that the γ's for each of the 25 plots are the same for a given species pair. The weighted (pooled) average of the G's is computed and called $\bar{G}$. Then, for each value of i where $i = 1, \ldots, I = 25$, the quantity $(G_i - \bar{G})^2 / s^2_{G_i}$. is compared with the critical value from the Chi-squared distribution for (I-1) degrees of freedom. Using the 5 per cent level of significance, the critical value for 24 degrees of freedom is 37.7. For both Tables 4 and 5, the computed value of the test statistic exceeds 37.7, and the hypothesis of equal values of γ is rejected.

One virtue of this procedure is that each plot's contribution to the total test statistic is displayed. Thus, it is possible to look for individual plots which contribute "more than their share" to the final value. In making this examination, recall that the critical value for 5 per cent level of significance for a single degree of freedom is 3.84. In Table 4, for instance, it is seen that

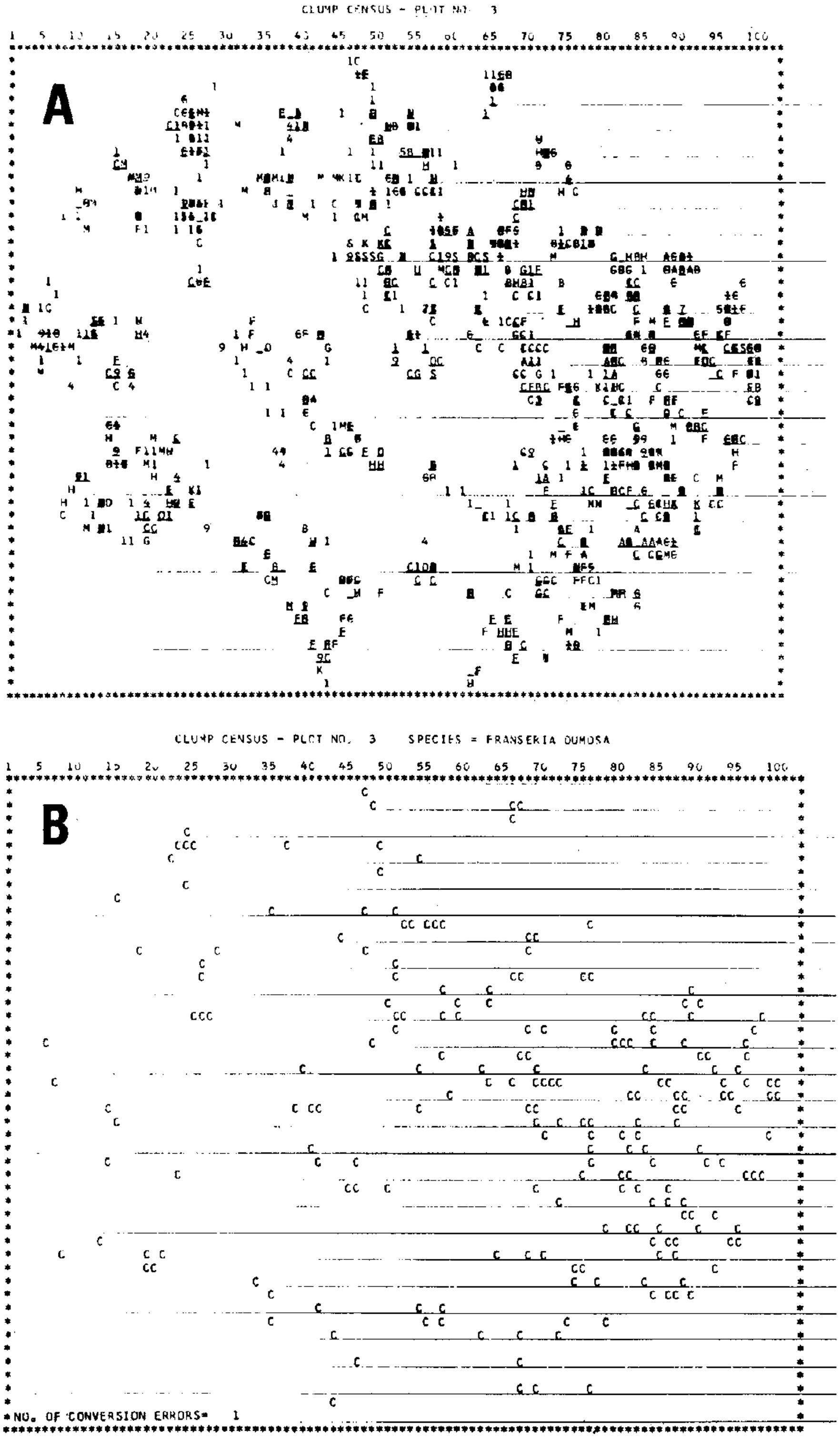


Figure 4. Schematic computer output showing the location of all shrub species (A) and a single species (B) in a sampled plot.

plots 1, 11, and 14 provide significant contributions to the total. Plots 1 and 11 indicate significantly larger values of G than $\bar{G} = 0.676$, while plot 14 has a significantly smaller G. (It must be kept in mind that these statistical techniques provide indicators. It is up to the subject matter expert to provide the meaningful interpretation.)

Again, space limitations prohibit the display of all these results. However, the $\bar{G}$ values usually are quite close to the combined estimates of γ which are shown for selected species pairs in Table 3, except for those species pairs in which there are significant differences between the plots as shown by a test of hypothesis of identical γ's.

A general view of the indications found in this study is provided by Table 6. The vegetational units in each plot were treated as a random sample of desert units. The null hypothesis in each case was $H_0:\gamma = 0$; i.e., the true association was zero. All statistical tests were performed at the 5 per cent level of significance. A species pair was declared *mutually exclusive* when all the observed frequencies fell in the top row and left-hand column of the two-way table; i.e., no vegetational units were found in which the two species appeared together. This latter condition corresponds to complete curvilinear counter association as described by Goodman and Kruskal (1954).

For a given species pair, then, one of four conclusions was reached for each plot, so that in each plot each species pair was declared to be:

(i) not statistically significantly associated,
(ii) statistically significantly positively associated,
(iii) statistically significantly negatively associated,
or (iv) mutually exclusive.

To illustrate, *Acamptopappus shockleyi* showed indicative G's with respect to 16 of the other 27 species present in the study area. It showed a positive association with three species and a negative association with eight species; it was mutually exclusive with five species. As another illustration, *Lycium andersonii* showed 19 positive, one negative, and four mutually exclusive measures of association.

Plants showing generally positive associations were *Ephedra funera*, *Ephedra nevadensis*, *Eurotia lanata*, *Franseria dumosa*, *Grayia spinosa*, *Krameria parvifolia*, *Larrea divaricata*, *Lycium andersonii*, *Sphaeralcea ambigua*, *Yucca schidigera*, and *Machaeranthera tortifolia*. Plants showing generally negative and mutual exclusiveness were *Acamptopappus shockleyi*, *Dalea fremontii*, *Hymenoclea salsola*, and *Menodora spinescens*. Among the grasses examined, *Oryzopsis hymenoides* showed the most positive association with other species. Several of the sparsely populated shrubs and herbaceous species were indicated as growing mutually exclusive of other species; these included *Coleogyne ramosissima*, *Encelia virginensis*, *Psilostrophe cooperi*, *Prunus fasciculata*, *Stephanomeria pauciflora* and *Thamnosma montana*. The low frequency of occurrence of these species may be responsible for some of these indications, and it will be of considerable interest to examine the associations of these plants in areas where they naturally occur at higher densities than in the Mercury Valley. These and other interrelationships are expected to be the subject of future reports.

Table 6. Indications of association for 28 perennial plants in desert hardpan soil at Mercury, Nevada.

Plant species	Significantly*		Mutually Exclusive**	Total
	Positive	Negative		
Acamptopappus shockleyi	3	8	5	16
Atriplex confertifolia	8	1	11	20
Cacti (mixed species)	13	0	8	21
Coleogyne ramosissima	1	0	20	21
Dalea fremontii	0	2	20	22
Encelia virginensis	3	0	24	27
Ephedra funerea	14	0	8	22
Ephedra nevadensis	14	0	8	22
Eurotia lanata	13	4	2	19
Franseria dumosa	17	2	3	22
Grayia spinosa	12	1	9	22
Hilaria rigida	3	2	14	19
Hymenoclea salsola	3	0	21	24
Krameria parvifolia	13	1	2	16
Larrea divaricata	12	1	7	20
Lepidium fremontii	6	0	9	15
Lycium andersonii	19	1	4	24
Machaeranthera tortifolia	13	0	6	19
Menodora spinescens	3	0	17	20
Oryzopsis hymenoides	10	0	8	18
Prunus fasciculata	3	0	20	23
Psilostrophe cooperi	1	0	23	24
Salazaria mexicana	11	0	9	20
Sphaeralcea ambigua	10	1	3	14
Stephanomeria pauciflora	4	0	19	23
Stipa speciosa	6	0	11	17
Thamnosma montana	1	0	23	24
Yucca schidigera	13	0	7	20
Totals	229	24	321	574

*Based on sampling assumption and test of $H_0{:}\gamma = 0$ at 5 per cent level of significance.

**Concentrated in first row and first column of two-way table.

Summary

A statistical method developed by Goodman and Kruskal (1954, 1963) has been used to provide quantitative measures of association among perennial plant species indigenous to desert hardpan soil in Mercury Valley at the Nevada Test Site. This technique has broad application in many kinds of ecosystems in which the matter of interest is the spatial distribution of the native species. The G-K method is particularly advantageous for dealing with data which can be arranged in a two-way table in which both variables of classification bear a "natural" ordering. Thus, the method is well-suited to dealing with variables which are discrete rather than continuous. Moreover, the statistical treatment is not dependent upon a particular method of determining the spatial distribution of plants in an area, therefore, it may be applied to quadrat studies for any kind of spatial distribution measurements which one might wish to employ.

The method employed for this study was based upon a complete census of all individuals in each of 25 plots. Since dispersion is of interest in future studies, polar coordinate location of plants and units was also undertaken as well as dimensional analysis for biomass studies.

Quantitative measures of association (the G values obtained under the assumption of random sampling of vegetational units) indicate that positive association exists among several different shrub species indigenous to the study site; subsequent subjective field inspection has corroborated many of these comparisons. Negative associations also are indicated among several prominent shrub species, a conclusion also confirmed by on-site visual inspection. A rather surprising number of shrubs of sparse density tend to grow mutually exclusive of other species in the study area, and the nature of their association in areas where they might occur at higher densities will be of interest in continuing studies.

Addendum A. Some Theoretical and Computational Details for the Goodman-Kruskal Measure of Association γ

It is the purpose of this Addendum to present, without reference to the specific desert species study described in the body of this report, some of the details underlying the theoretical development and computational procedures for the measure of association elucidated by Goodman and Kruskal (1954, 1963). The terminology is deliberately chosen to assist the user in reading their work. Another source of phrasing is the sampling study by Rosenthal (1966), who showed the applicability of the G-K γ to relatively small samples in 5 x 5 two-way tables.

An index of association called γ is suggested as appropriate in some situations where both classifications in a two-way table have intrinsic and relevant order. The definition of γ is

$$\gamma = \frac{\pi_s - \pi_d}{1 - \pi_t} = \frac{2\pi_s + \pi_t - 1}{1 - \pi_t} = \frac{\pi_s - \pi_d}{\pi_s + \pi_d} \qquad (A.1)$$

where

$$\begin{aligned}
\Pi_s &= 2\sum_a \sum_b \rho_{ab}\Big\{\sum_{a'>a}\ \sum_{b'>b} \rho_{a'b'}\Big\} \\
\Pi_d &= 2\sum_a \sum_b \rho_{ab}\Big\{\sum_{a'>a}\ \sum_{b'<b} \rho_{a'b'}\Big\} \qquad \text{(A.2)} \\
\Pi_t &= 1 - \Pi_s - \Pi_d = \sum_a \sum_b \rho_{ab}\{\rho_{a\cdot} + \rho_{\cdot b} - \rho_{ab}\} \\
&= \sum_a \rho_{a\cdot}^2 + \sum_b \rho_{\cdot b}^2 - \sum_a \sum_b \rho_{ab}^2.
\end{aligned}$$

In (A.2) the $\underline{\rho}_{ab}$ is the proportion of the population that is classified as both A_a and B_b in the general $\alpha \times \beta$ two-way table laid out on page 210 of the body of this report. Here, π_s ("s" for "same") is the probability that two randomly chosen individuals will have the same order in both classifications (called positive association or concordance), π_d ("d" for "different") is the probability that they will have different orders (called negative association or discordance), and π_t ("t" for "tie") is the probability that one or both classifications will be the same (order is not clearly defined).

Since, strictly speaking, (A.1) and (A.2) are in terms of computing formulas, another statement of meaning is worthwhile. In G-K's conceptual scheme, two individuals are drawn independently and at random with replacement from a population which is classified with respect to two dimensions A and B. The first individual has the values a_1 and b_1 for the variates A and B, and the second individual has the values a_2 and b_2. [a_i ($i = 1, 2$) takes the values $1, 2, \ldots, \alpha$ and b_i ($i = 1, 2$) takes the values $1, 2, \ldots, \beta$.] The A and B classifications are ordered. The following probabilities are defined:

$$\begin{aligned}
\pi_s &= \Pr\{a_1 < a_2 \text{ and } b_1 < b_2, \text{ or } a_1 > a_2 \text{ and } b_1 > b_2\}, \\
\pi_d &= \Pr\{a_1 < a_2 \text{ and } b_1 > b_2, \text{ or } a_1 > a_2 \text{ and } b_1 < b_2\}, \qquad \text{(A.3)} \\
\text{and} \quad \pi_t &= \Pr\{a_1 = a_2 \text{ or } b_1 = b_2\}.
\end{aligned}$$

The conditional probability of like orders given no ties is $\pi_s/(1 - \pi_t)$, and the conditional probability of unlike orders given no ties is $\pi_d/(1 - \pi_t)$. The measure of association is the difference between these two probabilities, $\gamma = (\pi_s - \pi_d)/(1 - \pi_t)$, which is the same as (A.1).

Suppose now that a random sample of size n is taken from this population, so that the cell frequencies in the $\underline{\alpha} \times \underline{\beta}$ table have a multinomial distribution. Let N_{ab} be the number of items in the sample which are classified as belonging to A_a and B_b. Then $R_{ab} = N_{ab}/n$ is the maximum likelihood estimator for ρ_{ab}. Hence, $0 \leq N_{ab} \leq n$.

It is suggested that γ be estimated by its maximum likelihood estimator

$$G = \frac{P_s - P_d}{1 - P_t} = \frac{2P_s + P_t - 1}{1 - P_t} = \frac{P_s - P_d}{P_s + P_d} \qquad \text{(A.4)}$$

in which P_s, P_d, and P_t are the sample analogs of the corresponding π's, as follows:

$$\begin{aligned}
P_s &= 2\sum_a \sum_b R_{ab}\{\sum_{a'>a} \sum_{b'>b} R_{a'b'}\} \\
&= \frac{2}{n^2}\sum_a \sum_b N_{ab}\{\sum_{a'>a} \sum_{b'>b} N_{a'b'}\}, \\
P_d &= 2\sum_a \sum_b R_{ab}\{\sum_{a'>a} \sum_{b'<b} R_{a'b'}\} \\
&= \frac{2}{n^2}\sum_a \sum_b N_{ab}\{\sum_{a'>a} \sum_{b<'b} N_{a'b'}\}, \qquad \text{(A.5)} \\
P_t &= 1 - P_s - P_d = \sum_a \sum_b R_{ab}\{R_{a\cdot} + R_{\cdot b} - R_{ab}\} \\
&= \frac{1}{n^2}\sum_a \sum_b N_{ab}\{N_{a\cdot} + N_{\cdot b} - N_{ab}\} \\
&= \sum_a R^2_{a\cdot} + \sum_b R^2_{\cdot b} - \sum_a \sum_b R^2_{ab} \\
&= \frac{1}{n^2}[\sum_a N^2_{a\cdot} + \sum_b N^2_{\cdot b} - \sum_a \sum_b N^2_{ab}].
\end{aligned}$$

$$N_{a\cdot} = \sum_b N_{ab}, \qquad N_{\cdot b} = \sum_a N_{ab}.$$

Note that the formulas in (A.5) are displayed in terms of both the R_{ab}'s and the N_{ab}'s. It is assumed that a tie is not certain; i.e., $\pi_t \neq 1$.

The measure G is a statistic. It is a function of sample values. Therefore, G has a variance. Call that variance σ^2_G. Goodman and Kruskal (1963) show that

$$\sigma^2_G = \frac{1}{n} \quad \frac{16}{(1-\Pi_t)^4}\{\Pi^2_s\Pi_{dd} - 2\Pi_s\Pi_d\Pi_{sd} + \Pi^2_d\Pi_{ss}\}, \qquad \text{(A.6)}$$

where

$$\begin{aligned}
\Pi_{ss} &= \sum_a \sum_b \rho_{ab}\{\sum_{a'>a} \sum_{b'>b} \rho_{a'b'} + \sum_{a'<a} \sum_{b'<b} \rho_{a'b'}\}^2 \\
\Pi_{dd} &= \sum_a \sum_b \rho_{ab}\{\sum_{a'>a} \sum_{b'>b} \rho_{a'b'} + \sum_{a'<a} \sum_{b'<b} \rho_{a'b'}\} \qquad \text{(A.7)} \\
&\qquad \cdot\{\sum_{a'>a} \sum_{b'<b} \rho_{a'b'} + \sum_{a'<a} \sum_{b'>b} \rho_{a'b'}\}, \\
\Pi_{sd} &= \sum_a \sum_b \rho_{ab}\{\sum_{a'>a} \sum_{b'<b} \rho_{a'b'} + \sum_{a'<a} \sum_{b'>b} \rho_{a'b'}\}^2.
\end{aligned}$$

The doubly-subscripted π's are interpreted as follows: Suppose three individuals are drawn at random and independently from the population.
Then

π_{ss} is the probability that the second and third individuals both have "positive" sign relationships (i.e., both are concordant) with the first,

π_{dd} is the probability that the second and third individuals both have "negative" sign relationships (i.e., both are discordant) with the first,

and π_{sd} is the probability that the second individual has "positive" sign relationships with the first (i.e., the first and second are concordant) but that the third has "negative" sign relationships with the first (i.e., the first and third are discordant).

If P_{ss}, P_{dd}, and P_{sd} are defined to correspond to π_{ss}, π_{dd}, and π_{sd} (so that R_{ab} corresponds to ρ_{ab}), and if $\underline{\sigma_G^2 \text{ of (A.6) is not zero}}$, it can be concluded that

$$(G - \gamma) \Big/ \sqrt{\frac{16}{n(1 - P_t)^4} \{P_s^2 P_{dd} - 2 P_s P_d P_{sd} + P_d^2 P_{ss}\}} \qquad \text{(A.8)}$$

is asymptotically normally distributed with zero mean and unit variance. Thus, (A.8) asymtotically is a standardized normal deviate for large values of the sample size n.

Because most data are collected and reported in terms of the cell frequencies, the N_{ab}'s, it is convenient to indicate the computing algorithm in terms of the observed frequencies. Some slight notational modifications are in order.

Define $\bar{P}_s = n^2 P_s$, $\bar{P}_d = n^2 P_d$, $\bar{P}_{ss} = n^3 P_{ss}$, $\bar{P}_{dd} = n^3 P_{dd}$, and $\bar{P}_{sd} = n^3 P_{sd}$. Then, in terms of the $\bar{P}$'s,

$$G = \frac{\bar{P}_s - \bar{P}_d}{\bar{P}_s + \bar{P}_d} \qquad \text{(A.9)}$$

and

$$s_G^2 = \frac{16\{\bar{P}_s^2 \bar{P}_{dd} - 2\bar{P}_s \bar{P}_d \bar{P}_{sd} + \bar{P}_d^2 \bar{P}_{ss}\}}{(\bar{P}_s + \bar{P}_d)^4} \qquad \text{(A.10)}$$

In terms of (A.9) and (A.10), the computations can be systematically described as follows, using a Goodman-Kruskal (1963) numerical example as an illustration.

First set down the N_{ab} table. Then compute what is called the S (for "same") table. This $\alpha \times \beta$ S table contains in its (a,b) cell the sum of all $N_{a'b'}$ such that $a' > a$ and $b' > b$, plus the sum of all $N_{a'b'}$ such that $a' < a$ and $b' < b$. Next, compute the D (for "different") table. This $\alpha \times \beta$ D table contains in its (a, b) cell the sum of all $N_{a'b'}$ such that $a' > a$ and $b' < b$, plus the sum of all $N_{a'b'}$ such that $a' < a$ and $b' > b$.

Thus, suppose the sample observation table contains 3 rows and 4 columns and n = 50:

N_{ab} Table

8	5	3	3
0	8	1	0
0	4	14	4

Then both the S and D tables contain 3 rows and 4 columns:

S Table

31	19	4	0
22	26	17	16
0	8	21	25

D Table

0	0	12	27
11	6	7	18
20	7	3	0

where, e.g., the 31 in the upper left corner of the S table is found by forming the sum $8 + 1 + 0 + 4 + 14 + 4 = 31$, and the 7 in the 2nd row and 3rd column of the D table is found by forming the sum $0 + 4 + 3 = 7$ (i.e., the elements below and to the left of the (2, 3) cell plus those above and to the right of the (2, 3) cell).

The component parts required for evaluation of (A.9) and (A.10) are constructed by manipulating the elements in the N_{ab}, S, and D tables according to the rules:

$\bar{P}_s$ is found by multiplying each entry of the N_{ab} table by the corresponding entry of the S table and adding the products; i.e., $\bar{P}_s = (8)(31) + (5)(19) + \ldots + (4)(25) = 1,006$.

$\bar{P}_d$ is found by multiplying each entry of the N_{ab} table by the corresponding entry of the D table and adding the products; i.e., $\bar{P}_d = (8)(0) + (5)(0) + \ldots + (4)(0) = 242$.

$\bar{P}_{ss}$ is found by multiplying each entry of the N_{ab} table by the square of the corresponding entry of the S table and adding the products; i.e.,

$$\bar{P}_{ss} = (8)(31)^2 + (5)(19)^2 + \ldots + (4)(25)^2 = 24,168 .$$

$\bar{P}_{dd}$ is found by multiplying each entry of the N_{ab} table by the square of the corresponding entry of the D table and adding the products; i.e., $\bar{P}_{dd} = (8)(0)^2 + (5)(0)^2 + \ldots + (4)(0)^2 = 3,278$.

$\bar{P}_{sd}$ is found by forming the sum of the triple products of corresponding terms from the N_{ab}, S, and D tables; i.e., $\bar{P}_{sd} = (8)(31)(0) + (5)(19)(0) + \ldots + (4)(25)(0) = 2,617$.

Use of these results in (A.9) and (A.10) yields

$$G = \frac{1,006 - 242}{1,006 + 242} = 0.612$$

and $$s_G^2 = \frac{16\ (1,006)^2(3,278) - 2(1,006)(242)(2,617) + (242)^2(24,168)}{(1,006 + 242)^4}$$

$$= .022812,$$

from which

$$s_G = .151.$$

This method of computing G, based on (A.9), is applicable to the computation of $\underline{\gamma}$ when the population proportions, the $\underline{\rho_{ab}}$'s, are known. Each ab table entry is converted from $\underline{\rho_{ab}}$ to an N_{ab} by multiplying $\underline{\rho ab}$ by an arbitrary value n. The algorithm then can be applied directly. Those who are algebraically adept may find it simpler to deal directly with the values of the $\underline{\rho_{ab}}$'s and make the appropriate adjustments. It is important only to recall that $\underline{\gamma}$ is then a population parameter, and there is no justification for the computation of something that would therefore be denoted $\underline{s^2_{\gamma}}$. However, in theoretical studies, it may be deemed useful to compute the true variance of G, $\underline{\sigma^2_G}$, using (A.10).

Addendum B. Testing Statistical Hypotheses Based on Estimates of the Goodman-Kruskal Measure of Association γ

It is the purpose of this addendum to provide additional details concerning the two statistical tests mentioned in the body of this report. A basic knowledge of the methods of testing statistical hypotheses is assumed, including fundamentals such as confidence intervals, levels of significance, and critical regions.

The normal (Gaussian) density function is defined by

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-(x-\mu)^2/2\sigma^2} . \qquad \text{(B.1)}$$

The constants μ and σ are parameters of the density function. They are commonly called the mean and standard deviation of the normal distribution. The square of the standard deviation is called the variance and generally is denoted by σ^2.

When $\mu = 0$ and $\sigma = 1$, the density (B.1) simplifies to

$$n(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2} . \qquad \text{(B.2)}$$

Then n(x) is called the standardized normal density function.

Let β be a number such that $0 < \beta < 1$. Then z_β is called the 100β-th percentile of the standardized normal density if the equation

$$\int_{-\infty}^{z_\beta} n(x)\,dx = \int_{-\infty}^{z_\beta} \frac{1}{\sqrt{2\pi}} e^{-x^2/2}\,dx$$

$$= \Pr\{x < z_\beta\} = \beta \qquad \text{(B.3)}$$

is satisfied. Because n(x) in (B.2) is symmetric about zero,

$$z_\beta = -z_{1-\beta}.$$

The ratio of the difference between G and γ to the estimated s_G (A.8) is normally distributed for large samples. Now choose an arbitrary number α such that $0 < \alpha < 1$. Employing (B.3), it can be stated that

$$\Pr\{z_{\alpha/2} < (G - \gamma)/s_G < z_{1-\alpha/2}\} = 1 - \alpha, \tag{B.4}$$

from which can be formalized as the $100(1-\alpha)$ per cent confidence interval

$$G - z_{1-\alpha/2}s_G < \gamma < G + z_{1-\alpha/2}s_G. \tag{B.5}$$

Among the commonly used α's and corresponding percentiles are:

α	$\alpha/2$	$1-\alpha/2$	$z_{1-\alpha/2}$
.01	.005	.995	2.576
.10	.050	.950	1.960
.20	.100	.900	1.645

This tabulation reveals that, as α increases, $z_{1-\alpha/2}$ decreases; hence, a confidence interval is narrowed at the expense of decreasing the degree of confidence.

Consider now the example at the end of Addendum A, for which $G = .612$ and $s_G = .151$ were obtained. A 95 per cent confidence interval is obtained by choosing $\alpha = .05$, for which $z_{1-\alpha/2} = z_{.95} = 1.960$.
Then, using (B.5),

$$.612 - (1.960)(.151) < \gamma < .612 + (1.960)(.151)$$

or

$$.316 < \gamma < .908 \tag{B.6}$$

is the desired confidence interval for γ.

The matter of testing a hypothesis about γ can be handled in terms of the confidence interval. Suppose it is desired to test the hypothesis that γ is equal to some particular value, say γ_0. In statistical parlance, this is stated as

$$H_0: \gamma = \gamma_0 ; \tag{B.7}$$

i.e., the hypothesis is that the measure of association in a particular two-way situation has the value γ_0. The hypothesis is accepted at the α level of significance if γ_0 lies between the endpoints of the interval computed by (B.5); otherwise, the hypothesis is rejected.

Suppose, using the example at the end of Addendum A, it is desired to test the hypothesis that the measure of association is .5. Then, because the inequality

$$.316 < .5 < .908 \tag{B.8}$$

is true, $H_0: \gamma = \gamma_0 = .5$ is accepted at the .05 level of significance. On the other hand, these same data lead to the rejection of the hypothesis that the measure of association is zero. That is, if $H_0: \gamma = \gamma_0 = 0$ is of interest, the hypothesis is rejected because zero lies in the critical (rejection) region. It is well to recall that independence between the two polytomies implies $\gamma = 0$, but that $\gamma = 0$ does not imply independence.

The second topic of this addendum concerns a method of comparing the γ's underlying several sets of sample data, a problem mentioned briefly on page 213. Suppose that several samples are collected from different populations. Let I be the number of samples, and let $G_1, \ldots, G_i, \ldots, G_I$ be the estimates of the corresponding γ_i's and $s_{G_1}, \ldots, s_{G_i}, \ldots, s_{G_I}$ be the corresponding estimated standard deviations. Suppose the equality of the γ_i's is of interest.

Formally, the hypothesis is stated

$$H_0: \gamma_1 = \ldots = \gamma_i = \ldots = \gamma_I. \tag{B.9}$$

Now, if the hypothesis is true, each sample G_i is an estimate of the same parameter. The best (minimum variance and unbiased) linear estimator of the common parameter is given by the weighted average of the G_i's, where the weights are the reciprocals of the variances of the G_i's themselves. Denote this estimator by $\bar{G}$, so that

$$\bar{G} = \frac{\sum_i \left(\frac{1}{s^2_{G_i}}\right) G_i}{\sum_i \left(\frac{1}{s^2_{G_i}}\right)} . \tag{B.10}$$

If the hypothesis is true, each quantity

$$\frac{(G_i - \bar{G})^2}{s^2_{G_i}} \tag{B.11}$$

is approximately distributed as a Chi-squared variable with a single degree of freedom. Moreover, the sum of all such quantities

$$S = \sum_i \frac{(G_i - \bar{G})^2}{s^2_{G_i}} \tag{B.12}$$

is approximately distributed as a Chi-squared variate with (I - 1) degrees of freedom.

Percentiles of the Chi-square distribution are not quite so simply tabulated as are percentiles for the normal distribution, but they can be found in most elementary and intermediate statistics textbooks. The 95th percentile for a single degree of freedom is, for instance, 3.84; this, of course, is the square of 1.96 which is the corresponding two-sided critical value for the normal distribution. Thus, any single term of the sum (B.12) which exceeds 3.84 indicates that the corresponding G_i is different from the value of γ which is estimated by $\bar{G}$.

With respect to S, the sum in (B.12), the hypothesis of equality is rejected if the critical value for (I - 1) degrees of freedom is exceeded.

An example of the calculations for this test is shown in Table 4 and is not repeated here. Nor is there any point in repeating the discussion contained in the section on results and discussion (see page 218).

In the event that the hypothesis of equal γ's is accepted, then $\bar{G}$ can be considered as a proper estimate of the common (but unknown) γ. Furthermore, the variance of $\bar{G}$ is estimated by

$$s^2_{\bar{G}} = \frac{1}{\sum_i \left(\frac{1}{s^2_{G_i}}\right)} \tag{B.13}$$

ESTIMATE OF PRIMARY PRODUCTIVITY IN THE ROCK VALLEY AREA OF THE NEVADA TEST SITE FOR 1966 - 1968

The primary purpose of this evaluation was to determine food supply for mammals living in the Rock Valley area. The goal of measuring primary productivity was not part of the original work plan and for this reason the data are not an exact expression of the primary productivity but are a good approximation.

Materials and Methods

The study was divided, for effective analysis, into two rather discrete parts. One, encompassing the annual plants within each of four plots (French, 1969), was conducted entirely within the plots while the shrub productivity was sampled outside the plots and then applied to the qualitative and quantitative shrub composition present in the plots. The annual plant study included the entire mature plant while that of the shrubs included leaf and fruit production only. Plant material is expressed as "standing crop" biomass and it most nearly represents net living material present at completion of the spring growing season. The annual plant portion of the study utilized transect lines existing in the plot (used in mammal studies). These parallel lines 15 meters apart were set in an east-west direction with stakes set at 15-meter intervals along these lines. We chose alternate stations along these transect lines giving 199 stations per plot. Quadrats are located 3 meters north of each station and this point became the lower right hand corner of each quadrat grid frame. The quadrat size was 2 by 5 decimeters with the long dimension of the quadrat pointing north. Each plant present in the quadrat grid was counted by species so that we reported species composition together with the species numbers for each quadrat.

In order to tie productivity into species composition and numbers it was necessary to have some fix on actual production of annual plant biomass. This meant that we needed to know how much an average plant of each species weighed. Although this was not a specific purpose of our study, collections of representative numbers of each species were made. This information was obtained only for the last year of the study. This sample collection was repeated in 1969 and data for 1968 and 1969 were used as an average for the three years of study. An error was incurred, therefore, for not having individual plant weights for 1966 and 1967. Sample size of the species varied from 25 to 500 plants depending on average plant size and available material at time of collection. Plants were wet and dry weighed and average species weights were derived. By applying these values to the actual sampling of plots, we arrived at "standing crop" for each species in each plot in kg per hectare. We then combined species to give the total annual biomass productivity at maturation. We endeavored to sample the annuals at peak maturity in late spring.

The shrub portion of the sampling was treated differently with the number one problem being the reluctance to remove sample material from within the plots. It might be well to say at this point that the purpose was to arrive at the inherent shrub composition and not to make any comparisons involving the irradiation factor in Plot B. An abundance study conducted by Martin in 1964 (see page 392) was used to establish species composition, density, average diameter and average volume within the plots. We utilized this data in applying our sample shrub measurements to the plots. For each of the major shrub species present in the plots (11 species) we sampled leaves and fruits in areas adjacent to the permanent study plots. The method was to establish, at random, transect lines for each species and to sample species individuals falling on these lines. Sampling for leaves and fruits was done separately on different lines and at time of peak maturity. Sample size was from five to ten individual plants with 1/4 plant being removed as a single sample. Sample size was limited by problems encountered in obtaining leaves or fruits at time of sampling. Some species did not fruit in some years. Also, the more dominant species were given first consideration. We measured mean diameter of each sampled specimen so that each species could be converted to an average size plant. All leaf material was carefully removed from the 1/4 plant sample, then wet and dry weighed. When the fruit for a species was mature, the same procedure as above was used to collect the fruit sample. Results gave a leaf and fruit weight for an average plant of each species.

The "Quarters Method" of sampling was used for measuring shrub abundance and density within each plot. Each sampling point was considered the center of four quarters, a predetermined compass line giving orientation. At each point the closest shrub to the point in each of the quarters was chosen. The species and diameter of each of these four shrubs was recorded and then the distance between the point and each of the four shrubs was measured. The sum of these distances divided by four equaled the average distance. This was done for each of the four Rock Valley sites.

The following definitions are used in the shrub data:
Relative density = Number of individuals of species per number of individuals all species times 100.
Relative dominance = Total basal area of species per total basal area all species times 100.
Relative frequency = Number of points of occurrence of species per number of points of occurrence of all species times 100.
Density or number of individuals per unit area = Unit area per distance squared.
Frequency = Number of points of occurrence of the species per total points.
Importance value = Relative density + relative dominance + relative frequency.

The final step was to take our weights and measurements and apply them to the qualitative and quantitative shrub composition present in each plot. These results gave a standing crop estimation of biomass for the major shrub species for plant leaf and fruit material.

We had information on winter annuals and shrubs for each of the plots for 3 years (1966 through 1968). We now made comparisons of various plant parameters to arrive at a value in weight per unit area for the combined standing crop biomass of leaf and fruit material for each species, plot, and year. Values for the three years were also plotted against cumulative monthly rainfall.

Beatley (1969) has already reported winter annual biomass production and some other plant characteristics (Beatley, 1966, 1970) for this particular area.

Results and Discussion

All leaf weight values of Ephedra nevadensis are primarily stem production. The annual leaf and fruit production for the shrub biomass in the four plots are shown in Table 1. Lycium pallidum and Krameria parvifolia varied greatly in the plots. The mean relative importance order for leaf weight production was L. divaricata (1.00) > L. andersonii (0.66) > E. nevadensis (0.55) > K. parvi-

Table 1. Dry matter production (kg/ha) of shrubs for the 4 plots (1966 - 1968).

Species name	Dry leaf	Fruit	Seed	Dry leaf	Fruit	Seed	Dry leaf	Fruit	Seed	Dry leaf	Fruit	Seed
	Plot — A			Plot — B			Plot — C			Plot — D		
				1966								
Ephedra nevadensis	45.8	0.0	0.00	52.6	0.0	0.00	65.3	0.0	0.00	51.5	0.0	0.00
Eurotia lanata	1.4	0.2	0.00	2.5	0.3	0.02	0.6	0.1	0.00	0.0	0.0	0.00
Grayia spinosa	4.3	0.8	0.05	20.7	4.1	0.27	2.1	0.4	0.03	15.6	3.1	0.23
Acamptopappus shockleyi	0.9	1.3	0.34	0.6	0.8	0.37	1.6	2.3	0.67	0.5	0.6	0.29
Franseria dumosa	13.2	14.2	0.59	12.9	13.9	0.63	11.2	12.1	0.48	13.4	14.5	0.73
Krameria parvifolia	80.5	14.1	0.12	9.1	1.6	0.02	52.3	9.1	0.08	16.0	2.8	0.03
Dalea fremontii	0.0	0.0	0.00	5.3	0.3	0.00	0.0	0.0	0.00	15.0	0.9	0.00
Coleogyne ramosissima	0.0	0.0	—	3.9	0.1	—	50.5	1.3	—	21.7	0.6	—
Lycium andersonii	150.2	27.0	4.77	85.5	15.4	3.48	174.1	31.3	5.53	56.5	10.2	2.51
Lycium pallidum	1.7	0.4	0.12	49.0	12.3	5.70	15.1	3.8	1.40	31.1	7.8	4.14
Larrea divaricata	164.3	12.1	1.52	131.6	9.7	1.54	185.8	13.7	1.71	86.3	6.4	1.13
				1967								
Ephedra nevadensis	56.9	0.6	0.00	65.3	0.7	0.00	81.0	0.8	0.01	63.8	0.7	0.01
Eurotia lanata	1.4	0.2	0.00	2.5	0.3	0.02	0.6	0.1	0.01	0.0	0.0	0.00
Grayia spinosa	4.3	0.3	0.04	20.7	1.3	0.19	2.1	0.1	0.02	15.6	1.0	0.17
Acamptopappus shockleyi	0.5	1.3	0.13	0.3	0.8	0.14	0.8	2.3	0.26	0.2	0.6	0.11
Franseria dumosa	18.1	12.0	0.18	17.7	11.7	0.19	15.4	10.2	0.14	18.4	12.2	0.22
Krameria parvifolia	38.6	1.1	0.01	4.4	0.1	0.00	25.0	0.7	0.00	7.7	0.2	0.00
Dalea fremontii	0.0	0.0	0.00	5.3	0.3	0.00	0.0	0.0	0.00	15.0	0.9	0.00
Coleogyne ramosissima	0.0	0.0	0.00	2.4	0.1	0.00	31.1	1.3	0.00	13.3	0.6	0.01
Lycium andersonii	71.7	0.3	0.08	40.8	0.2	0.06	83.1	0.3	0.09	27.0	0.1	0.04
Lycium pallidum	0.9	0.0	0.02	25.0	0.0	0.98	7.7	0.0	0.24	15.9	0.0	0.71
Larrea divaricata	103.7	0.0	0.05	83.1	0.0	0.06	117.2	0.0	0.06	54.4	0.0	0.04

Continued on next page.

Table 1 continued.

Species	Dry leaf	Fruit	Seed	Dry leaf	Fruit	Seed	Dry leaf	Fruit	Seed	Dry leaf	Fruit	Seed
		Plot — A			Plot —B			Plot — C			Plot — D	
							1968					
Ephedra nevadensis	69.0	0.2	0.00	79.2	0.3	0.00	98.3	0.3	0.00	77.5	0.3	0.00
Eurotia lanata	1.4	0.2	0.01	2.5	0.3	0.02	0.6	0.1	0.01	0.0	0.0	0.00
Grayia spinosa	4.3	0.3	0.04	20.7	1.3	0.19	2.1	0.1	0.02	15.6	1.0	0.17
Acamptopappus shockleyi	0.5	1.3	0.13	0.3	0.8	0.14	0.8	2.3	0.26	0.2	0.6	0.11
Franseria dumosa	19.4	6.3	0.32	18.9	6.1	0.34	16.4	5.3	0.26	19.7	6.4	0.40
Krameria parvifolia	72.0	1.1	0.01	8.2	0.1	0.00	46.8	0.7	0.00	14.4	0.2	0.00
Dalea fremontii	0.0	0.0	0.00	5.3	0.3	0.00	0.0	0.0	0.00	15.0	0.9	0.00
Coleogyne ramosissima	0.0	0.0	—	3.9	0.1	—	50.5	1.3	—	21.7	0.6	—
Lycium andersonii	89.7	10.1	1.71	51.1	5.7	1.25	104.0	11.7	1.99	33.7	3.8	0.90
Lycium pallidum	1.7	0.1	0.04	50.6	3.7	1.96	15.6	1.1	0.48	32.2	2.3	1.43
Larrea divaricata	158.6	9.2	1.52	127.1	7.4	1.54	179.4	10.4	1.71	83.3	4.8	1.13

Table 2. Plant shrub species values for entire plots from the earlier study of Martin and Hill (from Hill,1965).

Species name	Species compo-sition	Species vol (m^3/ha)	Species number (/ha)	Points occur (/ha)	Spec. area (m^2/ha)	Species rel. den.	Species freq.	Species rel. freq.	Species cover (%)	Species rel. dom.	Impor-tance value
	(%)					Species number / All species number x 100	Species points occurrence			Species basal area / All species area x 100	Rel. dom. + rel. den. + rel. freq.
							Total points	All sp. all pts. occur x 100			
				Plot —A							
Ephedra nevadensis	9.00	52.4	502.7	460.8	138	9.0	0.33	12.2	1.4	6.75	28.0
Eurotia lanata	0.50	0.3	27.9	27.9	1	0.5	0.02	0.7	0.0	0.05	1.3
Grayia spinosa	1.00	7.7	55.9	55.9	16	1.0	0.04	1.5	0.2	0.77	3.3
Acamptopappus shockleyi	1.00	0.4	55.9	27.9	2	1.0	0.02	0.7	0.0	0.12	1.8
Franseria dumosa	21.00	62.7	1173.1	782.0	218	21.0	0.56	20.7	2.2	10.72	52.4
Krameria parvifolia	34.30	58.4	1913.1	1061.3	356	34.2	0.76	28.0	3.6	17.48	79.7
Dalea fremontii	0.00	0.0	0.0	0.0	0	0.0	0.00	0.0	0.0	0.00	0.0
Coleogyne ramosissima	0.00	0.0	0.0	0.0	0	0.0	0.00	0.0	0.0	0.00	0.0
Lycium andersonii	17.50	327.8	977.5	684.3	681	17.5	0.49	18.1	6.8	33.42	69.0
Lycium pallidum	0.20	3.2	14.0	14.0	5	0.2	0.01	0.4	0.1	0.26	0.9
Larrea divaricata	15.50	375.0	865.8	670.3	620	15.5	0.48	17.7	6.2	30.42	63.6
Total	100.00		5586.0						20.5		

Species name	Species compo-sition (%)	Species vol (m^3/ha)	Species number (/ha)	Points occur (/ha)	Spec. area (m^2/ha)	Species rel. den.	Species freq.	Species rel. freq.	Species cover (%)	Species rel. dom.	Impor-tance value
						$\frac{\text{Species number}}{\text{All species number}} \times 100$	$\frac{\text{Species points occurrence}}{\text{Total points}}$	$\frac{\text{Species points occurrence}}{\text{All sp. all pts. occur}} \times 100$		$\frac{\text{Species basal area}}{\text{All species area}} \times 100$	Rel. dom. + rel. den. + rel. freq.
Plot —B											
Ephedra nevadensis	12.30	42.8	523.3	352.4	118	12.2	0.33	12.1	1.2	5.66	29.96
Eurotia lanata	2.30	4.4	96.1	74.8	14	2.2	0.07	2.6	0.1	0.66	5.46
Grayia spinosa	6.00	31.9	256.3	224.3	67	6.0	0.21	7.7	0.7	3.19	16.89
Acamptopappus shockleyi	1.30	1.0	53.4	42.7	5	1.2	0.04	1.5	0.1	0.25	2.95
Franseria dumosa	26.30	58.5	1132.1	556.0	206	26.5	0.53	19.4	2.1	9.89	55.79
Krameria parvifolia	5.80	10.7	245.6	213.6	58	5.7	0.20	7.3	0.6	2.80	15.80
Dalea fremontii	0.50	2.0	21.4	10.7	5	0.5	0.01	0.4	0.1	0.24	1.14
Coleogyne ramosissima	1.00	25.1	42.7	32.0	54	1.0	0.03	1.1	0.5	2.57	4.67
Lycium andersonii	15.00	331.6	640.8	491.3	592	15.0	0.46	16.8	5.9	28.38	60.18
Lycium pallidum	11.00	115.4	469.9	320.4	233	11.0	0.30	11.0	2.3	11.17	33.17
Larrea divaricata	18.50	553.8	790.3	587.4	734	18.5	0.55	20.1	7.3	35.19	73.79
Total	100.00		4272.0						20.9		

Table 2 continued.

Species name	Species compo-sition (%)	Species vol (m^3/ha)	Species number (/ha)	Points occur (/ha)	Spec. area (m^2/ha)	Species rel. den.	Species freq.	Species rel. freq.	Species cover (%)	Species rel. dom.	Impor-tance value
						Species number / All species number x 100	Species points occurrence / Total points	Species points occurrence / All sp. all pts. occur x 100		Species basal area / All species area x 100	Rel. dom. + rel. den. + rel. freq.
				Plot —C							
Ephedra nevadensis	11.50	49.6	652.1	581.2	148	11.5	0.41	14.6	1.5	6.35	32.45
Eurotia lanata	0.50	2.8	28.4	28.4	6	0.5	0.02	0.7	0.1	0.27	1.47
Grayia spinosa	0.50	3.0	28.4	28.4	9	0.5	0.02	0.7	0.1	0.37	1.57
Acamptopappus shockleyi	2.00	1.4	113.4	99.2	6	2.0	0.07	2.5	0.1	0.28	4.78
Franseria dumosa	17.00	66.6	964.0	538.7	169	17.0	0.38	13.5	1.7	7.22	37.72
Krameria parvifolia	23.00	41.4	1304.2	850.6	267	23.0	0.60	21.4	2.7	11.45	55.85
Dalea fremontii	0.00	0.0	0.0	0.0	0	0.0	0.00	0.0	0.0	0.00	0.00
Coleogyne ramosissima	5.50	56.7	311.9	184.3	127	5.5	0.13	4.6	1.3	5.44	15.54
Lycium andersonii	20.20	402.6	1148.3	822.2	822	20.2	0.58	20.6	8.2	35.22	76.02
Lycium pallidum	2.30	26.9	127.6	113.4	49	2.2	0.08	2.8	0.5	2.11	7.11
Larrea divaricata	17.50	446.5	992.3	737.2	730	17.5	0.52	18.5	7.3	31.28	67.28
Total	100.00		5670.4						23.5		

Table 2 continued.

Species name	Species composition (%)	Species vol (m^3/ha)	Species number (/ha)	Points occur (/ha)	Spec area (m^2/ha)	Species rel. den.	Species freq.	Species rel. freq.	Species cover (%)	Species rel. dom.	Importance value
						$\frac{\text{Species number}}{\text{All species number}} \times 100$	Species points occurrence $\frac{}{\text{Total points}}$	$\frac{}{\text{All sp all pts occur}} \times 100$		$\frac{\text{Species basal area}}{\text{All species area}} \times 100$	Rel. dom. + rel. den. + rel. freq.
				Plot —D							
Ephedra nevadensis	14.00	50.0	528.2	396.2	127	14.0	0.42	14.7	1.3	8.17	36.87
Eurotia lanata	0.00	0.0	0.0	0.0	0	0.0	0.00	0.0	0.0	0.00	0.00
Grayia spinosa	5.20	25.2	198.1	179.2	54	5.2	0.19	6.7	0.5	3.45	15.35
Acamptopappus shockleyi	1.00	0.7	37.7	37.7	3	1.0	0.04	1.4	0.0	0.20	2.60
Franseria dumosa	30.70	61.2	1160.2	688.6	205	30.7	0.73	25.6	2.0	13.19	69.49
Krameria parvifolia	10.80	15.5	405.6	273.6	85	10.7	0.29	10.2	0.9	5.51	26.41
Dalea fremontii	1.50	2.5	56.6	47.2	12	1.5	0.05	1.8	0.1	0.77	4.07
Coleogyne ramosissima	4.50	64.5	169.8	132.1	111	4.5	0.14	4.9	1.1	7.16	16.56
Lycium andersonii	10.80	186.3	405.6	339.6	344	10.7	0.36	12.6	3.4	22.19	45.49
Lycium pallidum	8.00	77.3	301.8	245.3	153	8.0	0.26	9.1	1.5	9.87	19.77
Larrea divaricata	13.50	337.9	509.4	349.0	458	13.5	0.37	13.0	4.6	29.50	56.00
Total	100.00		3773.0						15.4		

folia (0. 25) > *L. pallidum* (0. 17) > *C. ramosissima* (0. 14) > *F. dumosa* (0. 13) > *G. spinosa* (0. 09) > *D. fremontii* (0. 04) > *E. lanata* (0. 01) > *A. shockleyi* (0. 01).

The values in Table 2 are derived from data collected for the four plots in Rock Valley in the 1964 work of Martin and Hill. Measurements of standard shrub parameters have been applied to this data and presented here. Biomass calculations for the 3 years have been combined with plot species abundance data to give shrub production within each plot for each year.

In Table 2 the relative dominance was *L. divaricata* (1.00) > *L. andersonii* (0.84) > *F. dumosa* (0.32) > *K. parvifolia* (0.29) > *E. nevadensis* (0.21) > *L. pallidum* (0.18) > *C. ramosissima* (0.12) > *G. spinosa* (0.06).

The data in Table 3 represent a summary of "standing crop" biomass by plot for all the shrub species of Tables 1 and 2. Fruit, seed and leaf production varied greatly for the three years.

Table 3. Values of shrubs for total plot for 1966, 1967, and 1968.

Year	Ground cover	Total leaves	Total fruits	Total seeds	Leaf & fruit wt
	%,all species	kg/hectare			
		Plot — A			
1966	20.5	462.3	70.2	7.5	533
1967	20.5	296.0	15.7	0.5	312
1968	20.5	416.6	28.7	3.8	445
		Plot — B			
1966	20.9	373.7	58.5	12.0	432
1967	20.9	267.3	15.5	16.5	283
1968	20.9	367.7	26.2	5.5	394
		Plot — C			
1966	23.5	558.4	74.1	9.9	633
1967	23.5	364.0	15.8	8.3	380
1968	23.5	514.4	33.3	4.7	548
		Plot — D			
1966	15.4	307.5	46.8	9.1	354
1967	15.4	231.4	16.2	13.1	248
1968	15.4	313.2	20.9	4.1	334

The greatest amount of fruit production for the four plots and the 3 years was by *F. dumosa* (1.00) with *L. andersonii* (0.92) second, *L. divaricata* (0.59) third, *K. parvifolia* (0.25) fourth, *L. pallidum* (0.25) fifth, *A. shockleyi* (0.12) sixth, and *G. spinosa* (0.11) seventh.

Tables 4 to 6 represent the annual and perennial herbaceous plant production for each of the 3 years. The total production varied from year to year as did the species composition. Many species were absent in 1967.

Table 4. A study of annual and perennial herbaceous plant species numbers and composition (from one tenth meter square quadrats) for 1966. (199 quadrats per plot)

Species name	Total no. in grid	Prop. all plants	Dry wt kg/ha	Total no. in grid	Prop. all plants	Dry wt kg/ha
	Plot — A, 1966			Plot — B, 1966		
Festuca octoflora	678111	0.522	20.3	540880	0.277	16.2
Chaenactis carphoclinia	164878	0.127	29.7	143263	0.073	25.8
Pectocarya platycarpa	92493	0.071	17.6	83444	0.043	15.8
Phacelia fremontii	80931	0.062	17.8	317692	0.163	69.9
Gilia transmontana	66856	0.051	10.7	210622	0.108	33.7
Cryptantha recurvata	31166	0.024	8.7	32171	0.016	9.0
Langloisia setosissima	27647	0.021	1.1	110589	0.057	4.4
Thelypodium lasiophyllum	25134	0.019	4.3	81434	0.042	13.8
Oenothera munzii	20610	0.016	5.6	45744	0.023	12.3
Chorizanthe brevicornu	17594	0.014	1.4	60321	0.031	4.8
Chorizanthe rigida	17594	0.014	5.6	26139	0.013	8.4
Mentzelia veatchiana	12567	0.010	3.0	10054	0.005	2.4
Phacelia vallis-mortae	11562	0.009	5.2	46246	0.024	20.8
Ipomopsis polycladon	8546	0.007	0.5	44236	0.023	2.7
Gilia cana	7037	0.005	2.3	11562	0.006	3.7
Caulanthus cooperi	6535	0.005	1.2	14578	0.007	2.6
Eschscholzia glyptosperma	6032	0.005	1.3	2011	0.001	0.4
Bromus rubens	5027	0.004	0.9	11059	0.006	2.0
Descurainia pinnata	5027	0.004	1.4	14075	0.007	3.8
Astragalus tidestromii	2513	0.002	0.0	2011	0.001	0.0
Lepidium lasiocarpum	2011	0.002	0.6	1508	0.001	0.5
Eriogonum trichopes	1508	0.001	0.4	-	-	-
Stylocline micropoides	1508	0.001	0.0	34182	0.018	0.7
Eriophyllum pringlei	1508	0.001	0.1	-	-	-
Amsinckia tessellata	1005	0.001	0.5	3016	0.002	1.5
Lygodesmia exigua	1005	0.001	0.2	1005	0.001	0.2
Chaenactis fremontii	503	0.000	0.1	-	-	-
Machaeranthera tortifolia	503	0.000	0.0	503	0.000	0.0
Malacothrix glabrata	503	0.000	0.2	503	0.000	0.2
Mirabilis bigelovii	503	0.000	0.0	-	-	-
Oxytheca perfoliata	503	0.000	0.1	503	0.000	0.1
Linanthus demissus	-	-	-	62332	0.032	2.5
Linanthus bigelovii	-	-	-	11059	0.006	1.4
Antirrhinum filipes	-	-	-	10556	0.005	2.1
Eucrypta micrantha	-	-	-	8043	0.004	1.2
Rafinesquia neomexicana	-	-	-	3519	0.002	1.7
Plantago insularis	-	-	-	1508	0.001	0.2
Calycoseris wrightii	-	-	-	1005	0.001	0.2
Delphinium parishii	-	-	-	1005	0.001	2.2
Streptanthella longirostris	-	-	-	-	-	-
Eriogonum inflatum	-	-	-	-	-	-
Gilia clokeyi	-	-	-	-	-	-
Chaenactis macrantha	-	-	-	-	-	-
Unknown	-	-	-	1508	0.001	0.9

Table 4 continued.

Species name	Total no. in grid	Prop. all plants	Dry wt kg/ha	Total no. in grid	Prop. all plants	Dry wt kg/ha
	Plot — C, 1966			Plot — D, 1966		
Festuca octoflora	943525	0.617	28.3	435821	0.297	13.1
Chaenactis carphoclinia	53786	0.035	9.7	73894	0.050	13.3
Pectocarya platycarpa	96514	0.063	18.3	195039	0.133	37.0
Phacelia fremontii	55294	0.036	12.2	146279	0.100	32.2
Gilia transmontana	29155	0.019	4.7	42225	0.029	6.8
Cryptantha recurvata	25637	0.017	7.2	25134	0.017	7.0
Langloisia setosissima	34685	0.023	1.4	76910	0.052	3.1
Thelypodium lasiophyllum	36695	0.024	6.2	48760	0.033	8.3
Oenothera munzii	29658	0.019	8.0	29658	0.020	8.0
Chorizanthe brevicornu	59316	0.039	4.7	51776	0.035	4.1
Chorizanthe rigida	18599	0.012	5.9	70375	0.048	22.5
Mentzelia veatchiana	17594	0.012	4.2	5529	0.004	1.3
Phacelia vallis-mortae	13070	0.009	5.9	50268	0.034	22.6
Ipomopsis polycladon	9048	0.006	0.5	7037	0.005	0.4
Gilia cana	4021	0.003	1.3	4021	0.003	1.3
Caulanthus cooperi	5529	0.004	1.0	33679	0.023	6.1
Eschscholzia glyptosperma	3519	0.002	0.7	1508	0.001	0.3
Bromus rubens	29658	0.019	5.3	34685	0.024	6.2
Descurainia pinnata	3016	0.002	0.8	18096	0.012	4.9
Astragalus tidestromii	-	-	-	-	-	-
Lepidium lasiocarpum	4524	0.003	1.4	3519	0.002	1.1
Eriogonum trichopes	6032	0.004	1.5	8043	0.005	2.0
Stylocline micropoides	7037	0.005	0.1	2011	0.001	0.0
Eriophyllum pringlei	13572	0.009	0.8	37198	0.025	2.2
Amsinckia tessellata	-	-	-	2011	0.001	1.0
Lygodesmia exigua	2011	0.001	0.4	2011	0.001	0.4
Chaenactis fremontii	5529	0.004	1.2	11562	0.008	2.4
Machaeranthera tortifolia	-	-	-	503	0.000	0.0
Malacothrix glabrata	1005	0.001	0.4	503	0.000	0.2
Mirabilis bigelovii	-	-	-	-	-	-
Oxytheca perfoliata	1005	0.001	0.2	6032	0.004	1.0
Linanthus demissus	12567	0.008	0.5	37198	0.025	1.5
Linanthus bigelovii	-	-	-	-	-	-
Antirrhinum filipes	-	-	-	-	-	-
Eucrypta micrantha	-	-	-	-	-	-
Rafinesquia neomexicana	-	-	-	503	0.000	0.2
Plantago insularis	-	-	-	-	-	-
Calycoseris wrightii	503	0.000	0.1	1005	0.001	0.2
Delphinium parishii	-	-	-	1005	0.001	2.2
Streptanthella longirostris	3519	0.002	1.8	3519	0.002	1.8
Eriogonum inflatum	1005	0.001	0.9	-	-	-
Gilia clokeyi	1005	0.001	0.1	503	0.000	0.1
Chaenactis macrantha	503	0.000	0.1	-	-	-
Unknown	1508	0.001	0.9	-	-	-

Table 5. A study of annual and perennial herbaceous plant species numbers and composition (from one tenth meter square quadrats) for 1967. (199 quadrats per plot)

Species name	Total no. in grid	Prop.all plants	Dry wt kg/ha	Total no. in grid	Prop. all plants	Dry wt kg/ha
	Plot — A, 1967			Plot — B, 1967		
Festuca octoflora	860583	0.781	25.8	427778	0.766	12.8
Chaenactis carphoclinia	124664	0.113	22.4	56300	0.101	10.1
Pectocarya platycarpa	12064	0.011	2.3	2011	0.004	0.4
Phacelia fremontii	4524	0.004	1.0	1508	0.003	0.3
Gilia transmontana	-	-	-	1005	0.002	0.2
Cryptantha recurvata	2011	0.002	0.6	7037	0.013	2.0
Langloisia setosissima	2513	0.002	0.1	3016	0.005	0.1
Oenothera munzii	5529	0.005	1.5	4524	0.008	1.2
Chorizanthe brevicornu	10054	0.009	0.8	6032	0.011	0.5
Chorizanthe rigida	3519	0.003	1.1	1005	0.002	0.3
Mentzelia veatchiana	1005	0.001	0.2	1005	0.002	0.2
Phacelia vallis-mortae	-	-	-	4524	0.008	2.0
Gilia cana	-	-	-	503	0.001	0.2
Caulanthus cooperi	503	0.000	0.1	4021	0.007	0.7
Bromus rubens	63337	0.057	11.4	27647	0.050	5.0
Descurainia pinnata	2513	0.002	0.7	1508	0.003	0.4
Lepidium lasiocarpum	-	-	-	1005	0.002	0.3
Eriogonum trichopes	4524	0.004	1.1	1005	0.002	0.3
Lygodesmia exigua	-	-	-	-	-	-
Eriophyllum pringlei	-	-	-	-	-	-
Chaenactis fremontii	4021	0.004	0.8	503	0.001	0.1
Machaeranthera tortifolia	-	-	-	2011	0.004	0.0
Malacothrix glabrata	-	-	-	-	-	-
Mirabilis bigelovii	-	-	-	503	0.001	0.0
Linanthus demissus	-	-	-	-	-	-
Rafinesquia neomexicana	-	-	-	2513	0.005	1.2
Delphinium parishii	-	-	-	503	0.001	1.1
Lepidium fremontii	-	-	-	-	-	-
Chaenactis macrantha	503	0.000	0.1	-	-	-
Oryzopsis hymenoides	-	-	-	503	0.001	0.0
Unknown	-	-	-	503	0.001	0.3

Table 5 continued.

Species name	Total no. in grid	Prop. all plants	Dry wt kg/ha	Total no. in grid	Prop. all plants	Dry wt kg/ha
	Plot — C, 1967			Plot — D, 1967		
Festuca octoflora	591651	0.794	17.7	320205	0.611	9.6
Chaenactis carphoclinia	30161	0.040	5.4	38706	0.074	7.0
Pectocarya platycarpa	4021	0.005	0.8	9048	0.017	1.7
Phacelia fremontii	1508	0.002	0.3	1005	0.002	0.2
Gilia transmontana	-	-	-	-	-	-
Cryptantha recurvata	2011	0.003	0.6	2011	0.004	0.6
Langloisia setosissima	1508	0.002	0.1	1508	0.003	0.1
Oenothera munzii	5027	0.007	1.4	1508	0.003	0.4
Chorizanthe brevicornu	7540	0.010	0.6	14075	0.027	1.1
Chorizanthe rigida	503	0.001	0.2	1005	0.002	0.3
Mentzelia veatchiana	503	0.001	0.1	-	-	-
Phacelia vallis-mortae	503	0.001	0.2	1508	0.003	0.7
Gilia cana	-	-	-	-	-	-
Caulanthus cooperi	503	0.001	0.1	503	0.001	0.1
Bromus rubens	75402	0.101	13.6	105059	0.201	18.9
Descurainia pinnata	-	-	-	503	0.001	0.1
Lepidium lasiocarpum	-	-	-	1508	0.003	0.5
Eriogonum trichopes	12064	0.016	3.0	7037	0.013	1.8
Lygodesmia exigua	503	0.001	0.1	-	-	-
Eriophyllum pringlei	-	-	-	5027	0.010	0.3
Chaenactis fremontii	10556	0.014	2.2	9048	0.017	1.9
Machaeranthera tortifolia	-	-	-	503	0.001	0.0
Malacothrix glabrata	503	0.001	0.2	-	-	-
Mirabilis bigelovii	-	-	-	-	-	-
Linanthus demissus	503	0.001	0.0	503	0.001	0.0
Rafinesquia neomexicana	503	0.001	0.2	-	-	-
Delphinium parishii	-	-	-	503	0.001	1.1
Lepidium fremontii	-	-	-	2513	0.005	0.0
Chaenactis macrantha	-	-	-	-	-	-
Oryzopsis hymenoides	-	-	-	-	-	-
Unknown	-	-	-	503	0.001	0.3

Table 6. A study of annual and perennial herbaceous plant species numbers and composition (from one tenth meter square quadrats) for 1968. (199 quadrats per plot)

Species name	Total no. in grid	Prop. all plants	Dry wt kg/ha	Total no. in grid	Prop. all plants	Dry wt kg/ha
	Plot — A, 1968			Plot — B, 1968		
Bromus rubens	111092	0.033	20.0	68364	0.028	12.3
Festuca octoflora	2072537	0.613	62.2	1202403	0.497	36.1
Amsinckia tessellata	503	0.000	0.3	2011	0.001	1.0
Cryptantha circumscissa	13572	0.004	0.9	-	-	-
Cryptantha recurvata	-	-	-	37701	0.016	10.6
Cryptantha nevadensis	76910	0.023	0.0	-	-	-
Pectocarya platycarpa	256365	0.076	48.7	130193	0.054	24.7
Chaenactis carphoclinia	278986	0.083	50.2	139744	0.058	25.1
Chaenactis fremontii	5027	0.001	1.1	503	0.000	0.1
Chaenactis macrantha	1508	0.000	0.2	1508	0.001	0.2
Eriophyllum pringlei	1005	0.000	0.1	-	-	-
Lygodesmia exigua	1508	0.000	0.3	503	0.000	0.1
Machaeranthera tortifolia	-	-	-	503	0.000	0.0
Malacothrix glabrata	503	0.000	0.2	503	0.000	0.2
Stephanomeria exigua	1005	0.000	0.0	-	-	-
Stylocline micropoides	5027	0.001	0.1	21112	0.009	0.4
Caulanthus cooperi	12064	0.004	2.2	10054	0.004	1.8
Descurainia pinnata	38706	0.011	10.4	145776	0.060	39.3
Lepidium fremontii	-	-	-	-	-	-
Lepidium lasiocarpum	21112	0.006	6.8	8043	0.003	2.6
Streptanthella longirostris	8546	0.003	4.4	2513	0.001	1.3
Thelypodium lasiophyllum	25134	0.007	4.3	56300	0.023	9.6
Nama demissum	-	-	-	1005	0.000	0.0
Phacelia fremontii	27647	0.008	6.1	44236	0.018	9.7
Phacelia vallis-mortae	-	-	-	15080	0.006	6.8
Mentzelia veatchiana	10556	0.003	2.5	2513	0.001	0.6
Sphaeralcea ambigua	-	-	-	-	-	-
Oenothera munzii	59819	0.018	16.1	45744	0.019	12.3
Eschscholzia glyptosperma	-	-	-	1005	0.000	0.2
Gilia cana	503	0.000	0.2	3519	0.001	1.1
Gilia transmontana	41722	0.012	6.7	257371	0.106	41.2
Ipomopsis polycladon	116118	0.034	7.0	84952	0.035	5.1
Langloisia setosissima	100535	0.030	4.0	49765	0.021	2.0
Linanthus demissus	-	-	-	8043	0.003	0.3
Chorizanthe brevicornu	60321	0.018	4.8	58813	0.024	4.7
Chorizanthe rigida	24138	0.007	7.7	7037	0.003	2.3
Eriogonum maculatum	-	-	-	503	0.000	0.1
Eriogonum nidularium	-	-	-	503	0.000	0.1
Eriogonum trichopes	5529	0.002	1.4	7037	0.003	1.8
Oxytheca perfoliata	-	-	-	503	0.000	0.1
Delphinium parishii	-	-	-	503	0.000	1.1
Linanthus bigelovii	-	-	-	1005	0.000	0.1
Calycoseris wrightii	1508	0.000	0.3	1005	0.000	0.2
Rafinesquia neomexicana	1508	0.000	0.7	503	0.000	0.2
Unknown	-	-	-	-	-	-

Table 6 continued.

Species name	Total no. in grid	Prop. all plants	Dry wt kg/ha	Total no. in grid	Prop. all plants	Dry wt kg/ha
	Plot — C, 1968			Plot — D, 1968		
Bromus rubens	56300	0.017	10.1	199060	0.108	35.8
Festuca octoflora	2239426	0.657	67.2	943022	0.510	28.3
Amsinckia tessellata	2011	0.001	1.0	-	-	-
Cryptantha circumscissa	3519	0.001	0.2	8043	0.004	0.6
Cryptantha recurvata	-	-	-	-	-	-
Cryptantha nevadensis	50770	0.015	0.0	34182	0.018	0.0
Pectocarya platycarpa	235755	0.069	44.8	216654	0.117	41.2
Chaenactis carphoclinia	69369	0.020	12.5	58311	0.032	10.5
Chaenactis fremontii	20107	0.006	4.2	18096	0.010	3.8
Chaenactis macrantha	3016	0.001	0.5	2513	0.001	0.4
Eriophyllum pringlei	503	0.000	0.0	8043	0.004	0.5
Lygodesmia exigua	1005	0.000	0.2	1005	0.001	0.2
Machaeranthera tortifolia	-	-	-	503	0.000	0.0
Malacothrix glabrata	4021	0.001	1.6	503	0.000	0.2
Stephanomeria exigua	503	0.000	0.0	-	-	-
Stylocline micropoides	27647	0.008	0.6	6535	0.004	0.1
Caulanthus cooperi	14075	0.004	2.5	12567	0.007	2.3
Descurainia pinnata	212130	0.062	57.3	59316	0.032	16.0
Lepidium fremontii	-	-	-	1005	0.001	0.0
Lepidium lasiocarpum	4524	0.001	1.4	16086	0.009	5.1
Streptanthella longirostris	3519	0.001	1.8	10556	0.006	5.5
Thelypodium lasiophyllum	61327	0.018	10.4	48257	0.026	8.2
Nama demissum	-	-	-	-	-	-
Phacelia fremontii	38203	0.011	8.4	15583	0.008	3.4
Phacelia vallis-mortae	12567	0.004	5.7	10054	0.005	4.5
Mentzelia veatchiana	19604	0.006	4.7	-	-	-
Sphaeralcea ambigua	-	-	-	503	0.000	0.0
Oenothera munzii	55797	0.016	15.1	18599	0.010	5.0
Eschscholzia glyptosperma	-	-	-	-	-	-
Gilia cana	1508	0.000	0.5	503	0.000	0.2
Gilia transmontana	74899	0.022	12.0	29658	0.016	4.7
Ipomopsis polycladon	50268	0.015	3.0	13070	0.007	0.8
Langloisia setosissima	45744	0.013	1.8	27647	0.015	1.1
Linanthus demissus	2513	0.001	0.1	1508	0.001	0.1
Chorizanthe brevicornu	56300	0.017	4.5	32171	0.017	2.6
Chorizanthe rigida	14578	0.004	4.7	40214	0.022	12.9
Eriogonum maculatum	503	0.000	0.1	-	-	-
Eriogonum nidularium	503	0.000	0.1	1508	0.001	0.2
Eriogonum trichopes	21615	0.006	5.4	11059	0.006	2.8
Oxytheca perfoliata	-	-	-	-	-	-
Delphinium parishii	-	-	-	2513	0.001	5.5
Linanthus bigelovii	503	0.000	0.1	-	-	-
Calycoseris wrightii	-	-	-	-	-	-
Rafinesquia neomexicana	3519	0.001	1.7	-	-	-
Unknown	-	-	-	503	0.000	0.3

Table 7 presents combined shrub and annual plant biomass production as kg per hectare estimates on the dry weight basis for the 4 plots and the 3 years. The maximum differences among the 4 plots for each of the 3 years was 27% for 1966, 32% for 1967, and 36% for 1968 which was the year of highest productivity. Plot C gave the highest productivity for each of the 3 years and Plot D gave the lowest productivity for each of the 3 years.

Table 7. The estimated combined shrub and annual and perennial herbaceous biomass production (kg / hectare) (dry weight).

Year	Standing crop weights		
	Herbaceous	Shrubs	Both
	Plot — A		
1966	140	530	670
1967	70	310	380
1968	260	445	705
	Plot — B		
1966	260	430	690
1967	30	280	310
1968	250	395	645
	Plot — C		
1966	130	635	765
1967	40	380	420
1968	280	550	830
	Plot — D		
1966	210	355	565
1967	40	250	290
1968	200	335	535

Mean biomass production for 1966 and 1968 was about 650 kg per hectare and about 350 kg per hectare for 1967. Rosenzweig (1968) predicted about 600 kg per hectare for an area of 10 to 12 cm evapotranspiration per year.

The rainfall (July 1 through June 30 of each year and shown in 1/3 year sums) for the 3 years (Air Resources Laboratory Station in Rock Valley) is given in Table 8. The combined yearly production estimates, also shown, correspond well with late fall and winter rainfall (see also Beatley, 1969).

Summary

Estimates of net leaf and fruit production of shrubs and of net production of entire herbaceous plants were made for four plots each 9.12 hectares in area for 1966, 1967, and 1968 in the Rock Valley study area of the Nevada Test Site. Weights of annual plants were not obtained for 1966 and 1967 and so biomass expressions for annual plants in these 2 years were an average of annual plant weights taken in 1968 and 1969. Abundance and density values for annual plants in all 3 years had this 2-year weight average applied to them to give an approximation of net primary productivity as standing crop biomass.

Table 8. Rainfall for each year versus standing crop for each year. Rainfall is in cm and standing crop is in kg per hectare.

Year and month	Rainfall	Standing crop (combined plots average)		
		Herbaceous	Shrubs	Both
1965-1966				
July, August, September, October	1.46			
November, December, January, February	13.70			
March, April, May, June	1.25	185	487	672
1966-1967				
July, August, September, October	1.20			
November, December, January, February	4.47			
March, April, May, June	4.34	45	305	350
1967-1968				
July, August, September, October	6.89			
November, December, January, February	7.04			
March, April, May, June	1.60	247	431	678

The reported yearly biomass values for the herbaceous plants, therefore, would have somewhat broader fluctuations than our data would indicate. Measurements and weights were sampled at peaks of leaf and fruit maturity in late April, May, and early June of each year. Over the 3-year period shrub weights comprised about 75% of the total primary productivity measured and the magnitude of this percentage seemed to vary inversely with total rainfall. Annuals appeared to be more sensitive to low amounts of rainfall and to changes in seasonal distribution of rainfall than did shrubs. Species diversity of annuals, as well as size and numbers of individuals, decreased with failure of fall and winter rainfall in the 1966-1967 growing season. Numbers of plants were about 75% greater in 1968 than in 1966 but total dry weights remained nearly equal. Relative leaf production of the shrubs showed L. divaricata was greater than L. andersonii > E. nevadensis > K. parvifolia > L. pallidum > C. ramosissima > F. dumosa > G. spinosa > D. fremontii > E. lanata > A. shockleyi. Relative fruit production showed F. dumosa was greater than L. andersonii > L. divaricata > K. parvifolia > L. pallidum > A. shockleyi > G. spinosa > C. ramosissima > E. nevadensis > D. fremontii > E. lanata. In 1966 and 1968 primary production for the combined herbaceous and shrub biomass at the completion of the spring growing season was nearly equal while 1967 primary production estimates were about 50% of the 1966 and 1968 values. Net primary productivity totals were closely correlated with differences in fall and winter rainfall.

H. Kaaz collected these data and he is the principal author of this report.

ECOLOGICAL ATTRIBUTES OF PERENNIAL PLANTS IN THE NORTHERN MOJAVE DESERT

In a preceding section we presented a study of a measure of species association between pairs of perennial plants common to the northern Mojave Desert. It was pointed out that spatial relationships among plant species commonly are characterized in terms of association, dispersion, patterning, trend, etc. We present herein some results from continued studies on ecological attributes of perennial plants in our study plots near Mercury, Nevada. Included are data on plant dispersion (nearest neighbor), density, frequency, ground cover, and biomass calculated from non-destructive dimensional measurements.

Materials and Methods

A description of the Mercury Valley study plots and the field methods of analysis appears in a preceding section (p. 205). Methods used enabled us to determine the numbers, species composition, volume, area, weight, and spatial characteristics of each plant in terms of its presence as a solitary specimen or as a member of a clump of shrubs grouped together with interlocking foliage. We want to reiterate that the exact physical location of all shrubs in each of 25 plots was identified by polar coordinates in order that we might develop the spatial analysis studies of association and dispersion on a quantitative level. Field assessment data were transferred to punch cards for computer analysis.

Program for Determining Plant Dispersion

1. The raw data for this program were obtained from 25 sampled plots. Each plant location is a measured distance from the center of the plot at a measured angle clockwise from magnetic north.

2. The first computer program converts shrub locations from polar to cartesian coordinate locations by means of trigonometric functions so that the plot (treated as a 30.5 × 30.5 m square) has the zero position of X and Y in the upper left corner; the X and Y values for locating each shrub will be relative to this position (Figure 1). The plot number, species number, X value, Y value, and clump number (if the plant is a member of a group) are stored and manipulated in our next step as a single record unit.

3. The next step is a SORT program. The stored record units are separated by plot number and then by identification within each plot. Each species is then sorted into ascending order of its X values. If there are identical X values, then a sort into ascending order of Y values takes place. The integrity of the record unit is unaltered. The sorted group of units is again stored for the next manipulation.

4. The last step calculates, for each individual plant, the distance to the nearest plant of the same species and outputs the results (Figure 2). The logic of this maneuver follows:

a. Record units from the previous step are read into this step and manipulated by plot and by species. Species number, X axis value, Y axis value, and group value from each record unit are copied into separate subscripted vectors so that they may be treated separately but still maintain their unit integrity. For example, the X (5) element in our X vector contains the value of our

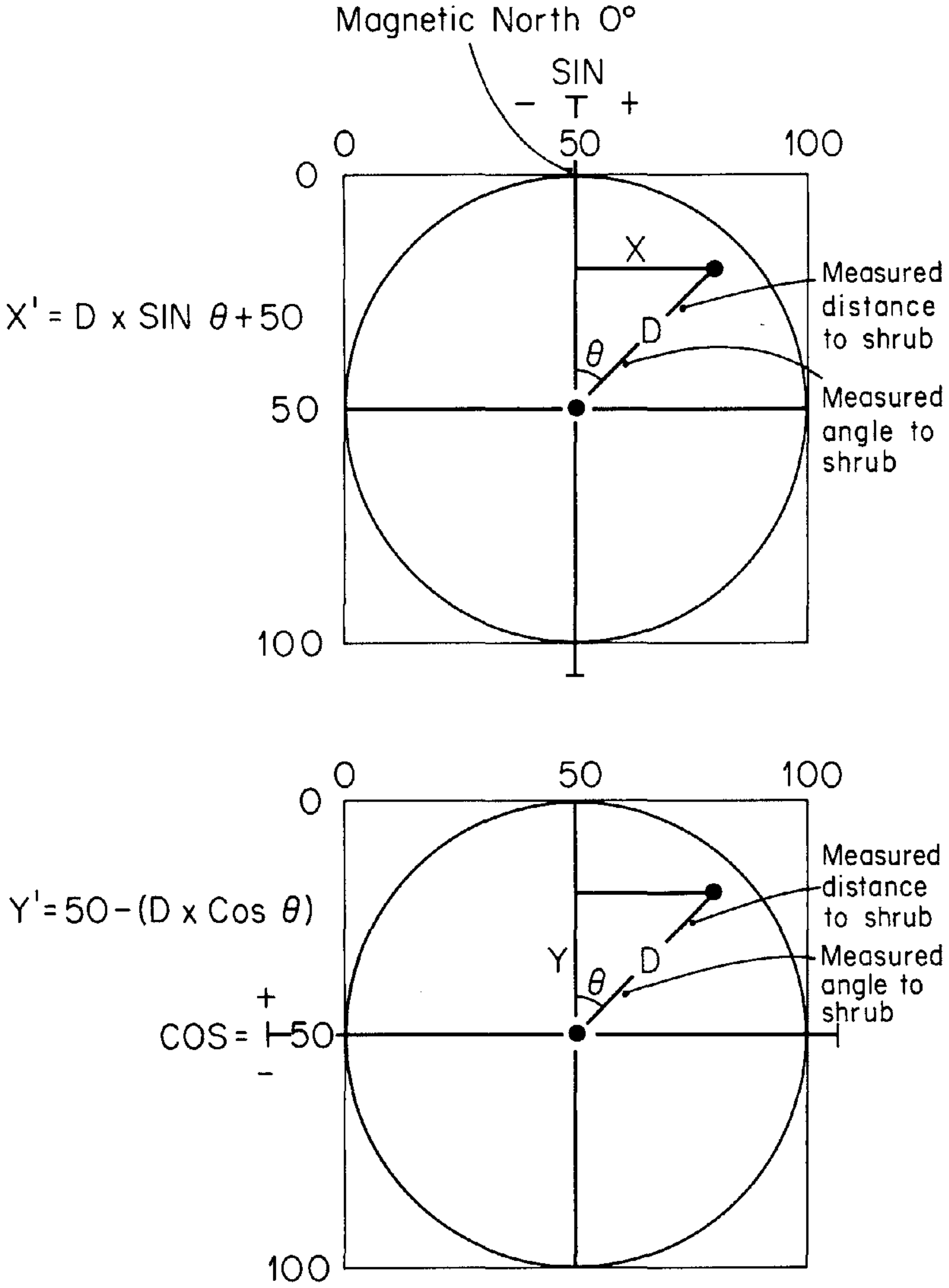


Figure 1. Conversion of plant location in each plot from polar to grid orientation so that plant location may be referenced by X and Y coordinates.

fifth sorted record unit value for X; the Y (5) element in our Y vector contains the value of our fifth sorted record unit value for Y.

b. We are now ready to search for the "nearest neighbor" of each individual plant of the same species within a plot. The plant with the smallest X will be chosen first and the order of search for the nearest neighbor will be to test, in ascending order, each species member by increasing size of its X value.

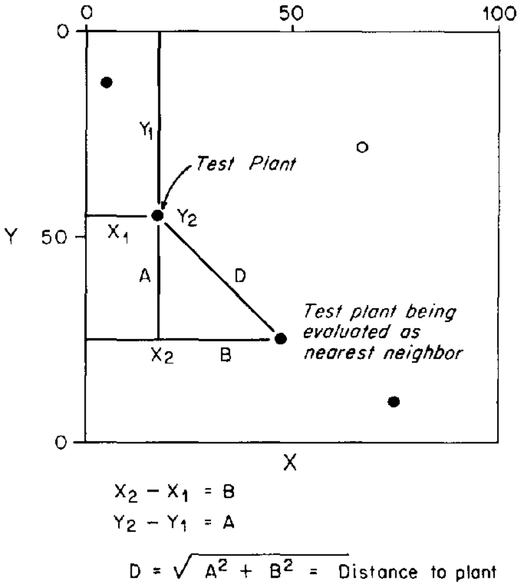


Figure 2. Calculation of the distance from test plant to nearest neighbor. The X's for each plant are sorted into an ascending order. For each iterative triangle solution we retain the smallest D value. When we reach the point where our new B is greater than the D we are retaining, we stop.

We then test, in like manner, by descending order. Obviously the first plant will have plants to the right in ascending order of X but will not have any plants to its left in descending order since it is the first plant. The actual nearest neighbor distance will be calculated as the hypotenuse of a right triangle using the difference of squares formula:

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$$

c. It is imperative to remember that we are always working with X values sorted in ascending order. The X side of our right triangle is derived from the difference between the X value of our chosen plant and the X value of the plant being tested as nearest. The Y side of our right triangle is derived from the difference between the Y value of our chosen plant and the Y value of the plant being tested as nearest. From our formula we can determine the hypotenuse which is the distance to the plant being tested as nearest.

d. We begin by giving our first hypotenuse a value greater than the plot dimension and by setting the X side of our triangle to zero. Now we start an iterative process whereby we first test the size of our side X against the size of our hypotenuse. We will repeat our test until side X is equal to or greater than our last previously held hypotenuse. We take the X value for the first plant in our Xn vector and we also take the next plant in order, which will have the next largest X value, and solve the difference of squares formula for these two plants. We retain two values, the hypotenuse which is the actual distance and the value for the X side of our triangle. We then test to see if this distance is less than the distance we initially placed into our hypotenuse. If this is true we exchange values and repeat our procedure retaining the smaller distance and our last X side value. We test side X against our distance again. As long as side X from our last triangle test is less than the distance (hypotenuse) we are retaining, we will continue to test additional plants against the one for whose value we are searching. Each time we iterate this process we check the new distance against the one we are holding and keep the smaller one. When side X of a triangle is equal to or greater than this distance, we know we have the minimum distance with the last retained hypotenuse and we stop. Now we must remember that, after the first X, we will have X values both larger and smaller than that of the plant we are testing so, using the same method as before, we must now search in descending order the X values smaller than the one we are solving for. When we reach the same end point as above, we will have the shortest distance from this plant to its nearest neighbor of the same species in the same plot.

e. We repeat this process by species and by plot for all individual plants. A modification of this program calculates the nearest plant of any species. Many combinations and comparisons are possible with this basic method. The collected information is output in the manner set forth in our PL/1 program.

Calculation of other Ecological Attributes

The calculations for most of the other attributes determined in this study simply involve mathematical permutation of raw field data. However, to assist in carrying out the more exact analysis regarding floristic systems, we began with a study of species composition and numbers. From this vantage point we then proceeded to the quantitative measurements of species in the stand. The analysis was plot by plot with a final summary.

1. Density. This is the average number of individuals per sampled area or per unit area. We have converted our plot numbers for each species to numbers per hectare.

2. Frequency. This is an expression of the percentage of sample plots in which a given species occurs. An estimate is obtained of the distribution of the species throughout the sample area. In this particular case we have a 100% census of the individuals of each species in each of our 25 plots, and our frequency value is a histogram type frequency distribution which tells us the percentage of each species present in terms of numbers of that species compared to the total number of individuals in the plot.

3. Relative Dominance. This is an analytical measure of plant importance in terms of basal area occupied by a species compared to basal area occupied by all species × 100 which yields an index of relative dominance.

4. Basal Area. Although density and frequency measurements provide analytical indexes, they do not give us any information regarding size which may be far more important in larger, less numerous species. Cover is the

term most often used to indicate the area occupied by a species; generally it is a measure of area covered by the crown of plant foliage. We have defined basal area as the mean area occupied by a species in a plot times the density of the species in the plot converted to m^2 per hectare.

5. Mean Individual Area. This is simply the mean area occupied by an individual of a given species in the plot.

6. Total Species Volume. This value is derived by using the formula for a cylinder and accepting the error resulting from the inadequacies of correct measurement. Volume was obtained for each species in each plot and converted to m^3 per hectare.

7. Mean Individual Volume. This value is given in m^3 for each species in each plot. It is the volume of an average plant.

8. Ground Cover. Because the plot census was 100%, we have been able to accumulate the areas of all individuals of each species, and to calculate the actual ground covered by each species as a per cent of the total plot area. We also obtained the total ground cover for all species.

9. Total Species Biomass. It was necessary to determine in some approximate manner the weight of above-ground material for each species in our sample plots, in order to relate plant volume to biomass. We did not wish to denude vegetation from our sampled plots so destructive sampling was done in the general area outside of the plots on a representative number of plants for the 12 most prominent species. We took height and width measurements and dry weights of the above-ground components so that we might use the dimensional measurements to obtain an estimate of standing crop biomass for each of the species sampled. We applied the volume and weight values to a BMDO5R

Figure 3. Plot of observed values and linear regression line used for estimating biomass from dimensional analysis for Lycium andersonii.

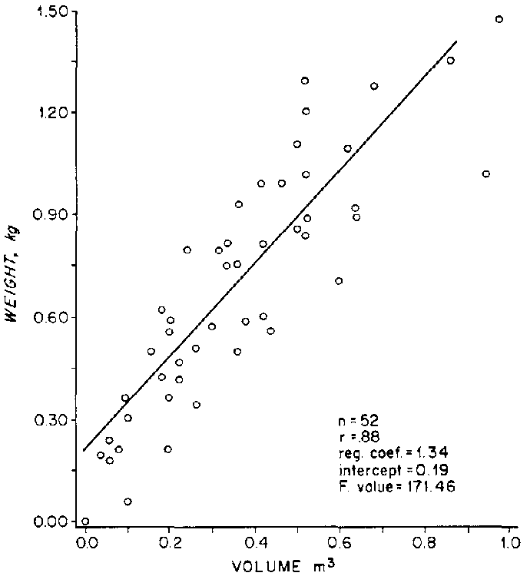


Table 1. Regression of dry weight (kg) on volume indexes (m^3) for 12 prominent shrub species in the Mercury plots.

Plant species	Sample size n	Correlation coefficient r	Regression W (kg) = aV - b	F value
Acamptopappus shockleyi	46	0.89	W = 2.36V + 0.004	159.74
Ephedra funerea	16	0.93	W = 1.64V - 0.030	94.94
Eurotia lanata	51	0.87	W = 2.16V - 0.002	149.69
Franseria dumosa	67	0.89	W = 2.13V + 0.001	250.16
Grayia spinosa	51	0.86	W = 1.69V + 0.043	136.19
Krameria parvifolia	34	0.86	W = 1.84V - 0.001	94.83
Larrea divaricata	33	0.91	W = 1.15V + 0.076	158.39
Lycium andersonii	52	0.88	W = 1.35V + 0.190	171.46
Machaeranthera tortifolia	13	0.99	W = 1.07V - 0.004	$>10^3$
Oryzopsis hymenoides	6	0.77	W = 0.52V + 0.022	5.96
Sphaeralcea ambigua	16	0.88	W = 0.33V + 0.001	46.20
Yucca schidigera	13	0.77	W = 3.04V + 0.458	6.41

Table 2. Dispersion of shrub species in one of the Mercury plots indicating the distance from a given species to its nearest neighbor of any species.

	Total	Group*	Solitary	Distance to nearest neighbor of any species			
Plant species	plants	plants	plants	Mean m	Std. dev. m	Group mean m	Solitary mean m
Acamptopappus shockleyi	219	73	146	1.03	0.88	1.23	0.92
Atriplex confertifolia	12	9	3	5.42	3.49	3.77	4.25
Ephedra funerea	9	9	0	6.97	2.72	6.96	0.00
Ephedra nevadensis	17	15	2	4.80	2.90	4.52	3.78
Eurotia lanata	4	4	0	5.91	3.95	5.91	0.00
Franseria dumosa	154	125	29	1.24	1.04	1.91	1.47
Grayia spinosa	15	14	1	3.77	3.01	3.95	1.27
Krameria parvifolia	35	33	2	3.04	2.69	3.01	0.29
Larrea divaricata	37	35	2	2.40	2.26	2.42	2.10
Lepidium fremontii	11	7	4	5.32	3.05	3.15	6.84
Lycium andersonii	33	30	3	3.34	2.13	3.34	3.27
Machaeranthera tortifolia	97	81	16	1.03	1.62	0.88	1.75
Oryzopsis hymenoides	5	4	1	5.38	3.50	4.80	4.62
Salazaria mexicana	9	9	0	2.23	3.89	2.84	0.00
Sphaeralcea ambigua	65	48	17	1.88	1.89	2.00	1.55
Yucca schidigera	10	8	2	2.36	3.83	2.75	0.79

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*Members of clumps of shrubs having interlocking foliage.

polynomial regression program. As an example, results for *Lycium andersonii* are illustrated in Figure 3. Although the computer program treated our values in both linear and quadratic fashion, we found no gain in significance using the quadratic form and our results are based on the BMD linear regression program. Table 1 contains a summary of regressions of dry weight on volume indexes for the 12 prominent shrub species. The correlation coefficients all have F values which are significant at the 5% level. These data were used to calculate the biomass for the 12 species in the Mercury plots which account for more than 95% of the total biomass.

Results and Discussion

Examples of plant dispersion data are shown in Tables 2 and 3. The data in Table 2 indicate the numbers of each species in a representative plot and the mean distance from a given specimen to its nearest neighbor of any species. The results are classified according to species occurrence, as solitary plants or members of a group or clump. The differences in plant dispersion are

Table 3. Dispersion of shrub species in the combined Mercury plots indicating the distance from a given species to its nearest neighbor of the same species (for all 25 plots).

	Total	Group*	Solitary	Distance to nearest neighbor of same species			
	plants	plants	plants	Mean	Std. dev.	Group mean	Solitary mean
Plant species				m	m	m	m
Acamptopappus shockleyi	3601	1711	1890	1.14	1.12	1.10	1.16
Atriplex confertifolia	149	117	32	2.93	2.46	2.94	2.97
Cactus (not identified)	69	57	12	8.21	5.63	7.74	10.41
Coleogyne ramosissima	10	9	1	1.54	2.82	1.60	0.96
Dalea fremontii	26	9	17	7.19	5.37	8.72	6.37
Ephedra funerea	268	228	40	4.80	3.54	4.67	5.56
Ephedra nevadensis	399	341	58	3.13	3.33	2.81	4.96
Eurotia lanata	4285	3780	505	0.96	1.13	0.93	1.18
Franseria dumosa	4206	3285	921	1.17	1.03	1.13	1.30
Grayia spinosa	505	488	17	2.84	3.15	2.82	3.45
Hilaria rigida	62	39	23	0.74	1.91	1.02	0.29
Krameria parvifolia	1718	1362	356	1.94	1.63	1.99	1.73
Larrea divaricata	1272	1133	139	2.12	2.01	2.15	1.86
Lepidium fremontii	57	45	12	4.69	3.68	5.13	3.06
Lycium andersonii	1126	1093	33	2.44	1.91	2.42	3.14
Machaeranthera tortifolia	267	233	34	2.03	2.61	1.89	2.93
Menodora spinescens	24	20	4	4.59	5.53	4.72	3.92
Oryzopsis hymenoides	228	186	42	3.42	3.83	3.07	4.93
Psilostrophe cooperi	5	2	3	1.82	2.54	0.39	2.80
Salazaria mexicana	114	104	10	1.83	3.73	1.95	0.53
Sphaeralcea ambigua	1377	891	486	1.93	1.81	1.94	1.91
Stipa speciosa	108	101	7	1.83	2.57	1.83	1.88
Yucca schidigera	183	162	21	5.52	3.88	5.46	5.98

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*Members of clumps of shrubs having interlocking foliage.

Table 4. Some ecological attributes of shrub species in one of the Mercury plots measured by nondestructive, dimensional analyses.

Plant species	No. ind.	Spec. dens. #/ha	Spec. freq. %	Rel. dom.	Total basal area m^2/ha	Mean ind. area m^2	Total spec. volume m^3/ha	Mean ind. volume m^3	Total spec. biomass kg/ha	Mean ind. biomass kg	Ground cover %
Acamptopappus shockleyi	219	3000.0	0.298	7.5	126.0	0.042	25.6	0.009	18.3	0.006	1.3
Atriplex confertifolia	12	164.4	0.016	0.8	13.1	0.080	4.2	0.025	0.00	0.000	0.1
Ephedra funerea	9	123.3	0.012	4.2	70.7	0.574	44.2	0.358	68.71	0.557	0.7
Ephedra nevadensis	17	232.9	0.023	5.5	92.7	0.398	57.0	0.245	0.00	0.000	0.9
Eurotia lanata	4	54.8	0.005	0.1	1.3	0.024	0.3	0.005	0.49	0.009	0.0
Franseria dumosa	154	2109.6	0.209	29.1	485.8	0.230	194.5	0.092	413.78	0.196	4.9
Grayia spinosa	15	205.5	0.020	1.9	31.1	0.151	14.9	0.072	34.00	0.165	0.3
Krameria parvifolia	35	479.5	0.048	8.1	135.6	0.283	29.2	0.061	53.34	0.111	1.4
Larrea divaricata	37	506.8	0.050	14.3	239.8	0.473	204.3	0.403	273.22	0.539	2.4
Lepidum fremontii	11	150.7	0.015	0.2	3.7	0.024	0.8	0.005	0.00	0.000	0.0
Lycium andersonii	33	452.1	0.045	13.7	229.0	0.507	101.9	0.225	223.50	0.494	2.3
Machaeranthera tortifolia	97	1328.8	0.132	2.3	37.9	0.028	11.2	0.008	13.80	0.010	0.4
Oryzopsis hymenoides	5	68.5	0.007	0.0	0.3	0.005	0.1	0.002	1.57	0.023	0.0
Salazaria mexicana	9	123.3	0.012	3.1	52.3	0.424	36.5	0.296	0.00	0.000	0.5
Sphaeralcea ambigua	65	890.4	0.088	2.0	33.8	0.038	9.8	0.011	4.16	0.005	0.3
Yucca schidigera	10	137.0	0.014	6.6	110.5	0.806	123.0	0.898	1158.90	8.460	1.1

Table 5. Ecological attributes of shrub species in one of the Mercury plots reflecting group association and solitary plant status.

Plant species	No. group ind.	No. sol. ind.	Group dens. #/ha	Sol. dens. #/ha	Group freq. %	Sol. freq. %	Group basal area m^2/ha	Sol. basal area m^2/ha	Group vol. m^3/ha	Sol. vol. m^3/ha	Group bio-mass kg/ha	Sol. bio-mass kg/ha	Group grnd. cover %	Sol. grnd. cover %
Acamptopappus shockleyi	73	146	1000.0	2000.0	0.144	0.638	67.8	58.2	15.0	10.6	7.5	10.5	0.7	0.6
Atriplex confertifolia	9	3	123.3	41.1	0.018	0.013	10.0	3.1	3.4	0.8	0.0	0.0	0.1	0.0
Ephedra funerea	9	0	123.3	0.0	0.018	0.000	70.7	0.0	44.2	0.0	68.7	0.0	0.7	0.0
Ephedra nevadensis	15	2	205.5	27.4	0.030	0.009	92.7	0.0	57.0	0.0	0.0	0.0	0.9	0.0
Eurotia lanata	4	0	54.8	0.0	0.008	0.000	1.3	0.0	0.3	0.0	0.5	0.0	0.0	0.0
Franseria dumosa	125	29	1712.3	397.3	0.247	0.127	430.1	55.7	172.9	21.6	367.8	46.0	4.3	0.6
Grayia spinosa	14	1	191.8	13.7	0.028	0.004	30.0	1.1	14.4	0.5	32.6	1.4	0.3	0.0
Krameria parvifolia	33	2	452.1	27.4	0.065	0.009	133.6	2.1	29.0	0.2	53.0	0.4	1.3	0.0
Larrea divaricata	35	2	479.5	27.4	0.069	0.009	207.2	32.6	176.3	28.0	239.0	34.2	2.1	0.3
Lepidium fremontii	7	4	95.9	54.8	0.014	0.017	2.4	1.2	0.5	0.3	0.0	0.0	0.0	0.0
Lycium andersonii	30	3	411.0	41.1	0.059	0.013	213.6	15.4	97.5	4.5	209.6	13.9	2.1	0.2
Machaeranthera tortifolia	81	16	1109.6	219.2	0.160	0.070	34.4	3.5	10.6	0.6	13.6	0.2	0.3	0.0
Oryzopsis hymenoides	4	1	54.8	13.7	0.008	0.004	0.2	0.2	0.1	0.0	1.2	0.3	0.0	0.0
Salazaria mexicana	9	0	123.3	0.0	0.018	0.000	52.3	0.0	36.5	0.0	0.0	0.0	0.5	0.0
Sphaeralcea ambigua	48	17	657.5	232.9	0.095	0.074	23.7	10.1	7.0	2.8	3.0	1.2	0.2	0.1
Yucca schidigera	8	2	109.6	27.4	0.016	0.009	109.2	1.2	122.8	0.3	927.1	231.8	1.1	0.0

Table 6. Ecological attributes of shrub species in the combined Mercury plots reflecting group association and solitary plant.

	No. ind.	Dens. #/ha	Ground cover %	Ind. mean area m^2	Total basal area m^2/ha	Ind. mean vol. m^3	Total vol. m^3/ha	Group nos.	Sol. nos.	Group area m^2/ha	Sol. area m^2/ha	Group vol. m^3/ha	Sol. vol. m^3/ha	Group biomass kg/ha	Sol. biomass kg/ha	Total spec. biomass kg/ha	Mean ind. biomass kg
Acamptopappus shockleyi	3601	1967.8	1.0	0.053	104.5	0.012	23.7	1711	1890	71.3	33.2	17.5	6.2	7.9	5.6	13.5	0.007
Atriplex confertifolia	150	82.0	0.1	0.080	6.6	0.028	2.3	118	32	5.6	1.0	2.0	0.2	0.0	0.0	0.0	0.000
Ephedra funerea	269	147.0	0.8	0.539	79.3	0.384	56.4	228	41	74.0	5.2	53.0	3.4	83.2	5.0	88.2	0.600
Ephedra nevandesis	399	218.0	0.7	0.332	72.5	0.171	37.4	341	58	68.4	4.1	35.8	1.5	0.0	0.0	0.0	0.000
Eurotia lanata	4286	2342.1	1.9	0.081	190.4	0.035	82.8	3781	505	176.0	14.4	78.1	4.7	164.4	9.7	174.1	0.074
Franseria dumosa	4206	2298.4	4.0	0.174	400.9	0.065	150.0	3285	921	340.8	60.1	131.5	18.5	279.8	39.3	319.1	0.139
Grayia spinosa	506	276.5	0.5	0.166	46.0	0.092	25.4	489	17	45.1	0.9	25.0	0.4	53.9	1.0	54.9	0.199
Krameria parvifolia	1718	938.8	2.6	0.272	255.1	0.056	52.8	1362	356	221.7	33.4	47.2	5.6	86.2	10.2	96.4	0.103
Larrea divaricata	1272	695.1	2.9	0.418	290.6	0.308	213.9	1133	139	270.8	19.8	200.1	13.8	277.0	21.7	298.6	0.430
Lepidum fremontii	62	33.9	0.0	0.036	1.2	0.013	0.5	48	14	1.0	0.2	0.4	0.0	0.0	0.0	0.0	0.000
Lycium andersonii	1126	615.3	2.9	0.465	285.9	0.215	132.4	1093	33	279.0	6.9	129.7	2.7	288.6	7.1	295.7	0.481
Machaeranthera tortifolia	270	147.5	0.0	0.030	4.5	0.009	1.3	235	35	4.2	0.3	1.3	0.1	1.7	0.0	1.7	0.011
Oryzopsis hymenoides	228	124.6	0.0	0.014	1.7	0.005	0.6	186	42	1.6	0.1	0.6	0.0	2.5	0.5	3.1	0.025
Salazaria mexicana	117	63.9	0.2	0.250	16.0	0.134	8.6	106	11	15.7	0.4	8.4	0.1	0.0	0.0	0.0	0.000
Sphaeralcea ambigua	1378	753.0	0.3	0.036	27.3	0.010	7.4	892	486	17.5	9.8	5.0	2.4	2.2	1.1	3.2	0.004
Yucca schidigera	183	100.0	1.2	1.166	116.6	1.717	171.7	162	21	103.3	13.4	148.6	23.0	748.9	97.1	846.0	8.460
Combined species totals	20108	10988.0	19.2		1916.2		974.6	15430	4678	1710.0	206.0	890.8	83.8	1996.3	198.3	2194.5	

much greater between species than they are between solitary or grouped specimens of the same species. The data in Table 3 summarize the dispersion for the combined plots in terms of the mean distance from a given specimen to its nearest neighbor of the same species. Here again, the differences caused by group or solitary occurrence generally were insignificant compared to the differences between species. Plant species showing greatest dispersion generally were of low density in the plots, as one might expect. They included some unidentified specimens of cactus, Dalea fremontii, Yucca schidigera, Ephedra funerea, Menodora spinescens and Lepidium fremontii.

Table 4 contains results of ecological attributes of perennial plants for one of the Mercury Valley plots with some of these data reclassed according to group or solitary occurrence in Table 5. Space will not permit including data for all 25 plots; however, the results for the combined plots have been summarized in Table 6. Nine perennial plant species account for most of the floristic characteristics in Mercury Valley. They are, in order of decreasing biomass, Yucca schidigera, Franseria dumosa, Larrea divaricata, Lycium andersonii, Eurotia lanata, Krameria parvifolia, Ephedra funerea, Grayia spinosa, and Acamptopappus shockleyi. The shrub species contributing the most ground cover are Franseria dumosa (4%), Larrea divaricata (2.9%), and Lycium andersonii (2.9%), followed closely by Krameria parvifolia (2.6%). The shrubs of highest density include Eurotia lanata, Franseria dumosa, and Acamptopappus shockleyi, respectively. It appears to be ecologically significant that seedlings of these three species are the ones most commonly found in the sampled plots. In summary, our quantitative analysis of perennial plants of the northern Mojave Desert in Mercury Valley indicated a mean density of 10,988 per hectare, 19.2% ground cover, and an above-ground biomass of 2,194 kg per hectare of which about 90% is contributed by plants growing together in clumps in group association.

Summary

Some ecological attributes of perennial plants native to the northern Mojave Desert were analyzed for study plots in Mercury Valley, Nye County, Nevada. Shrubs contributing the most ground cover on the study plots are Franseria dumosa, Larrea divaricata, and Lycium andersonii. These shrubs and 25 less common perennials, herbs, and grasses form discrete clumps of vegetation separated by bare areas of desert pavement. The size and spacing is irregular, and as many as ten different species may congregate with interlocking foliage. Non-destructive measurements, including spatial identity, heights and diameters were made of all perennial plants in 25 plots, each 30.5 m in diameter. From these measurements, quantitative determinations were made of species dispersion, density, frequency, ground cover, and several other attributes. Shrubs were collected from adjacent areas, measured, dismembered, oven dried, and weighed. Regressions of above-ground biomass on volume indexes were calculated for 12 species estimated to contribute more than 95% of the total perennial plant biomass. These regressions were used to determine the total standing crops of these plants in the Mercury Valley study plots.

THE *LARREA DIVARICATA* ECOTONAL LINE NEAR THE FRENCHMAN FLAT PLAYA

The bajadas draining into playas of closed basins in southern Nevada often have an ecotonal demarcation line below which *Larrea divaricata* does not grow (Figure 1). Various hypotheses have been presented for this phenomenon and these include low temperature (Beatley, 1965), salinity (Shreve, 1940; Shantz and Piemeisel, 1940), fine textured soil (Gardner, 1951; Branson et al., 1967), and excess water (Fosberg, 1940; Shreve and Wiggins, 1964).

Figure 1. *Larrea divaricata* ecotone line near the playa of Frenchman Flat.

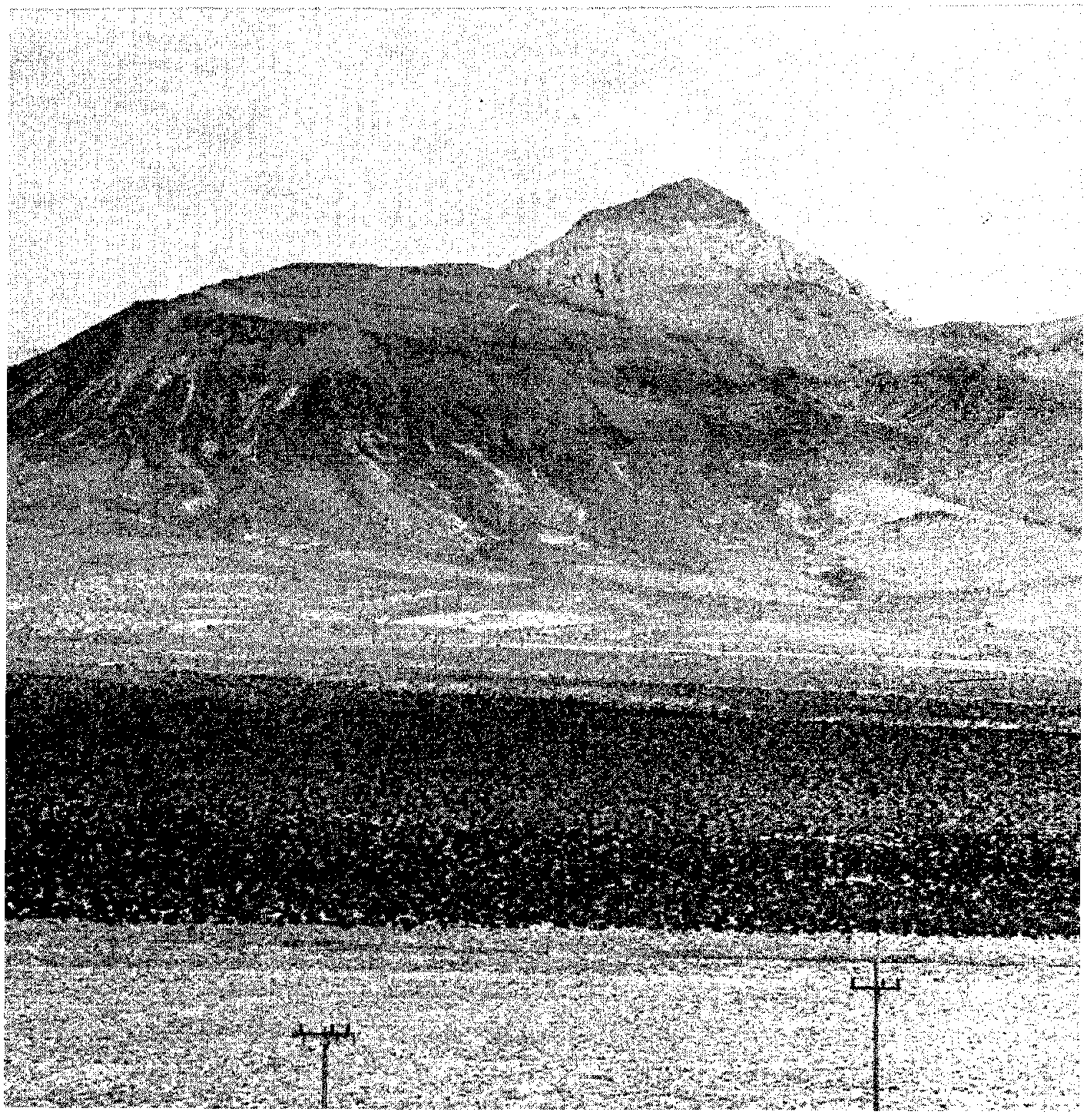


Table 1. Distribution of plant species in a 15 x 500 m transect across a Larrea-Atriplex ecotone in west Frenchman Flat.

Species	Number of plants in 15 X 50 m segments*									
	1	2	3	4	5	6	7	8	9	10
L. divaricata	0	1	0	0	0	11	38	54	59	59
E. lanata	284	354	310	135	45	146	111	145	204	234
A. canescens	64	33	21	74	101	41	3	7	0	0
A. confertifolia	2	1	0	0	2	0	0	0	0	0
H. salsola	167	48	53	132	145	61	1	0	0	0
A. shockleyi	159	63	72	18	9	10	28	44	32	37
G. spinosa	35	55	60	22	23	20	75	105	147	182
L. andersonii	13	13	13	5	4	15	8	31	46	89
L. pallidum	81	91	84	85	63	44	16	4	0	0
T. axillaris	13	10	10	12	19	30	6	0	0	1
O. hymenoides	90	39	40	61	27	53	56	139	37	40
F. dumosa	110	115	82	43	13	39	50	159	140	173
A. spinescens	56	41	105	114	29	11	5	0	0	0
S. pestifera	22	9	0	8	13	0	0	0	0	0

*Segments are numbered from lower to higher elevation, i.e., away from the playa.

The distribution of plant species in the transition zone of the Larrea-Atriplex ecotone at Frenchman Flat was examined at two different locations several km apart. Data from 15 X 500 m transects across the ecotone are given in Tables 1 and 2. There is a definite trend for the density of some plant species to be inversely related to that of L. divaricata, and the distribution data also disclosed that the ecotone exists for other species as well as for L. divaricata. The factors which regulate the distribution of L. divaricata also would appear to regulate the distribution of some other species. The two sites selected for study were chosen because of their apparent diversity in subdominant species associations in the Larrea-Atriplex ecotone line. Vegetation at the west Frenchman Flat site was more complex and the terrain features suggested greater possibilities of diversity in edaphic factors than might occur at the north Frenchman Flat site. We had not made sufficient progress on studies

Table 2. Distribution of plant species in a 15 x 500 m transect across a Larrea-Atriplex ecotone line in north Frenchman Flat.

Species	Number of plants in 15 x 50 m segments*									
	1	2	3	4	5	6	7	8	9	10
L. divaricata	0	0	1	0	3	28	54	40	75	55
E. lanata	1	1	2	4	6	25	10	52	84	99
F. dumosa	0	0	14	23	29	47	16	96	168	263
P. subspinosa	0	2	1	1	4	6	11	26	29	59
A. canescens	202	240	192	183	246	149	100	75	47	54
S. pestifera	56	44	56	42	54	18	0	0	0	1
L. andersonii	0	0	0	1	0	0	1	3	5	2
S. ambigua	203	256	129	126	121	49	106	50	61	37

*Segments are numbered from lower to higher elevation.

Table 3. Mineral composition of plant leaves from areas on transect across *Larrea* ecotonal line in north Frenchman Flat.

Location	Species	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Co	Ni	Mo	Sr	Ba
		% of dry weight						ppm of dry weight											
Playa	*A. canescens*	.15	.028	6.41	2.68	.88	.15	45.7	4.6	200	79	49	386	6	1.6	2.3	1.4	144	17
below	*M. pudica*	.29	.013	4.16	5.17	2.31	.22	63.2	7.7	232	190	85	235	3	T	T	14.0	296	21
ecotone	*O. hymenoides*	.19	.018	2.11	0.58	.21	1.67	25.6	10.4	469	186	37	452	10	T	T	2.5	68	41
	S. ambigua	.51	.117	3.62	3.43	.60	.67	45.5	7.4	1098	158	128	2683	35	2.6	4.8	2.2	282	56
Larrea	*A. canescens*	.15	.045	8.03	3.79	1.14	.25	55.9	6.2	327	125	60	713	14	1.7	2.7	1.4	217	26
ecotone	*F. dumosa*	.43	.081	5.63	3.38	.53	.45	47.7	5.5	664	87	129	1337	43	1.6	3.0	2.6	343	31
line	*L. divaricata*	.29	.026	2.53	1.63	.19	.30	40.4	4.0	451	44	76	691	16	T	1.8	1.0	149	20
	E. lanata	.18	.099	3.38	1.67	.43	.34	31.7	3.7	740	101	49	879	21	0.9	1.8	1.2	163	18
	O. hymenoides	.19	.009	2.06	0.44	.15	1.73	27.1	7.4	327	138	42	283	8	T	T	2.7	74	26
	S. ambigua	.71	.128	3.34	2.97	.53	.84	40.6	6.9	1412	251	159	2975	44	2.6	5.8	2.1	252	49
Bajada	*A. canescens*	.14	.041	8.58	3.65	1.05	.18	50.4	5.1	288	86	51	394	10	2.7	3.6	2.3	163	17
above	*F. dumosa*	.49	.133	6.15	3.79	.72	.43	55.0	6.4	482	102	129	821	12	3.7	5.7	2.0	351	15
Larrea	*L. divaricata*	.25	.092	2.05	1.93	.24	.43	44.4	3.1	533	59	84	1076	8	2.1	4.6	1.2	195	17
ecotone	*E. lanata*	.21	.075	5.59	2.93	.74	.37	46.1	5.6	551	119	51	973	10	1.5	3.7	1.1	172	16
	M. pudica	.33	.043	3.76	3.98	1.91	.31	47.5	7.9	372	106	67	776	17	2.4	3.1	7.1	268	16

of edaphic factors at these sites to include results in this report; some preliminary examinations of the soil profiles, however, indicated some marked differences in texture and particle size in the lower horizons.

At the west Frenchman Flat site (Table 1) the *L. divaricata* line tended also to be a *Grayia spinosa* line, but to a lesser extent since the *G. spinosa* did not disappear like *L. divaricata* does; fewer plants are encountered at the lower end of the transect. *Lycium andersonii* behaves similarly. *Atriplex canescens*, perhaps *Atriplex confertifolia*, *Hymenoclea salsola*, *Lycium pallidum*, *Tetradymia axillaris*, *Artemisia spinescens*, and *Salsola pestifera* behave oppositely to *L. divaricata*. Since some of these species form associations elsewhere with *L. divaricata*, the amplitude of each must be involved. This ecotone line is complex and indicates that microenvironmental factors may be involved.

At the north Frenchman Flat ecotone line (Table 2) the situation is much simpler. The distribution pattern of *Eurotia lanata* and *Franseria dumosa* across the ecotone is much like *L. divaricata* which did not occur at the west Frenchman Flat site. Different factors, therefore, must be involved. Another species, *Polygala subspinosa* behaved like the *L. divaricata* also. *A. canescens* diminished less abruptly into the *Larrea* ecotone than occurred at the west Frenchman Flat site; simple competition could explain part of this effect. *S. pestifera* grew where the *L. divaricata* did not and this may indicate some type of soil disturbance. Since *E. lanata* distribution paralleled *L. divaricata*, one might conclude that soil salinity is not the causal factor involved in this particular ecotone inasmuch as *E. lanata* can grow in moderately saline soil (Vest, 1962) but *L. divaricata* does not. On the other hand, sensitivity of seeds and young seedlings to soil salinity and pH could be one of the limiting causal factors involved at these ecotones either at the present time or in early periods when the population initially became established.

Preliminary checks on the upper 0.5 m of the soil profile at the extreme ends of our transects showed soil pH values ranging from 8.7 to 9.0 for both sites. The soil conductance values of 1:1 soil extracts were relatively low, ranging from 0.23 to 0.34 mmhos/cm ($Ec \times 10^3$ at 25°C). Soils in this area are generally calcareous and relatively low in exchangeable sodium. For example, a soil sample collected earlier near the west Frenchman Flat site had pH 8.6; cation exchange capacity, 9.98; extractable cations: Na 0.48, K, 2.32; Ca, 83.56; Mg, 6.58 me/100 g; and carbonates, 33 per cent. The upper soil profile in these areas does not appear to be saline-alkali; conditions at lower depths are not yet known but they are being investigated. In some recent work, Barbour (1968), observed that *L. divaricata* seed germination was not affected by soil pH but that seedling root growth was markedly decreased with increasing pH, especially above pH 8.0. The lack of young *L. divaricata* in the ecotonal area suggests that seedling survival is a rare event which may be regulated by the high soil pH levels now present. We do, however, see size stratification within the shrub population indicating that favorable conditions for seedling survival have periodically occurred, presumably many decades apart. There is certainly the possibility that the pH of soil on or near the playas of these closed basins has gradually increased over the centuries from accumulated salts so that new *L. divaricata* seedlings now rarely survive.

Mineral contents of leaf samples from shrubs growing at the two study sites are given in Tables 3 and 4. Results are revealing with respect to differences in the accumulation of a given element in leaves of different species growing at the same site. Samples of shrubs which grew at both ends of the 500 m transects did not vary greatly in mineral content. Perhaps plant analyses will be more revealing when they can be correlated with the chemical characteristics

Table 4. Mineral composition of plant leaves from transect area across Larrea ecotonal line in east Frenchman Flat.

Location	Species	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Ti	Co	Ni	Mo	Sr	Ba
		% of dry weight						ppm of dry weight											
Playa	A. canescens	.29	.114	11.88	2.31	.73	.19	33.1	5.4	214	64	40	255	9	4.4	5.3	2.4	79	16
below ecotone	S. pinnata	.22	.063	4.87	3.82	.51	.13	36.7	3.8	156	77	57	137	6	3.2	3.6	11.2	214	16
Larrea	F. dumosa	.34	.100	3.82	3.92	.73	.31	38.9	3.6	317	69	128	559	8	3.5	5.1	1.9	318	22
ecotonal	K. parvifolia	.40	.133	1.51	1.45	.32	.12	25.2	4.9	133	45	53	79	2	1.8	3.5	T	84	10
line	L. divaricata	.28	.046	2.44	2.07	.24	.44	30.1	2.6	533	61	65	958	12	1.6	3.2	T	166	22
	L. andersonii	.15	.022	4.63	9.45	1.82	.15	56.3	2.2	147	43	82	163	5	2.6	3.0	6.3	301	48
	L. shockleyi	.26	6.147	0.73	1.57	.71	.22	12.5	4.6	273	82	49	366	18	1.8	1.6	2.5	57	16
	A. confertifolia	.17	6.770	4.36	3.97	.72	.22	34.9	4.6	248	93	63	392	11	3.4	4.0	1.9	109	17
Bajada	F. dumosa	.32	.081	4.32	4.11	.56	.26	38.3	3.8	196	54	113	369	9	2.2	2.3	2.2	265	10
above	K. parvifolia	.34	.072	1.71	1.78	.29	.10	14.2	2.9	79	35	57	41	1	2.4	4.9	1.2	133	10
ecotone	L. divaricata	.15	.070	2.00	1.95	.21	.23	22.3	2.6	275	45	69	371	10	1.6	3.6	1.1	145	11
	L. andersonii	.16	.100	4.55	9.95	1.25	.15	53.6	2.6	162	61	95	181	5	4.0	4.2	9.7	778	37

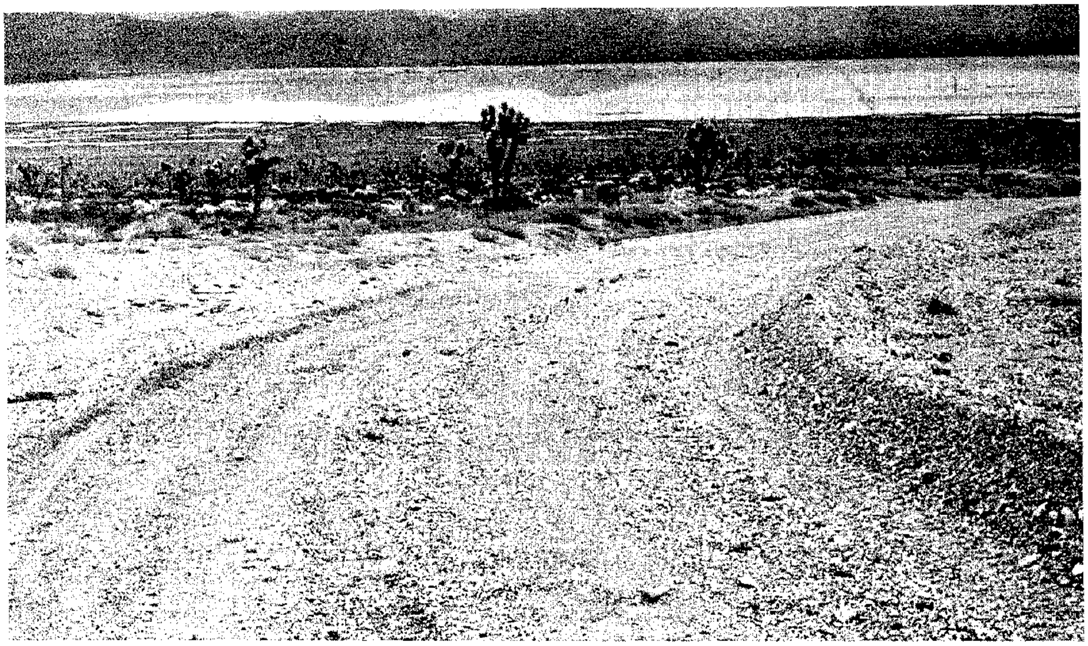


Figure 2. Flooding of closed basin floors after heavy rains and snow melts.

and physical properties of soils on which they grow. Data in the tables may suggest a reason for distribution of Lycium species.

Another factor which might be involved in regulating the distribution of L. divaricata and some other species near the playas of closed basins is periodic flooding of the basin floor beyond the boundaries of the apparent dry lake bed. Such an event occurred in several of these closed basins in southern Nevada and southeastern California after unusually heavy rains and snow melts in 1969 (Figure 2). Shrub species sensitive to poor root aeration or standing water on foliage could be damaged when inundated with flood water. L. divaricata is a species known to require good aeration of the root zone and well-drained soils (Shreve and Wiggins, 1964). Complete inundation need not necessarily be affected; a higher than normal water table might be just as detrimental to some sensitive species.

An interesting case in point occurred in 1969 when unusually heavy spring runoff filled the terminal basin of the Mojave River watershed located just north of Baker, California (Figure 2). Standing water inundated vegetation for several months and an investigation the following year showed a band of apparently dead shrubs, from 100 to 200 m wide in places surrounding the dry lake playa. The last time this basin had flooded to this extent was in 1937 according to California Highway Department information. Ring counts in some of the stems of the largest dead Atriplex species varied from 33 to 37 growth rings indicating that these shrubs had established themselves near the playa in the 32-year interval between floods.

Not all Larrea ecotone lines are related to playas. The one shown in Figure 3 is related to air drainage or to maximum and minimum temperatures. It is a south-facing slope near the northern limit of the test site and near the northern limit for L. divaricata (Beatley, 1965).

Summary

An analysis has been made of the vegetation across the Larrea divaricata ecotone line in Frenchman Flat above the playa at two different locations. Dif-

Figure 3. A L. divaricata ecotone line (near middle of picture and running across it) due to temperature; it is on a south-facing slope looking north from Pahute Mesa Road 1 mile west of Orange Road at the Nevada Test Site.

ferences exist for the two transects. Franseria dumosa and Eurotia lanata numbers varied inversely with L. divaricata in one location but not in the other. Atriplex canescens numbers varied opposite to that of L. divaricata at both locations. Artemisia spinescens was at one location only, and was negatively correlated with L. divaricata. Distribution of Lycium pallidum which is salt tolerant varied oppositely to L. divaricata and Lycium andersonii tended to vary directly with it. Mineral analyses of plants for the 2 ecotone lines are given. The relationship of Larrea ecotone lines to various environmental factors is discussed.

ARTEMISIA, EUROTIA, AND JUNIPERUS ECOTONAL LINES ON PAHUTE MESA

Ecotonal lines involving different shrub species are common in the Great Basin and Mojave Deserts. The patterning of vegetation in these deserts characteristically may include large areas which are occupied continuously by a single type of vegetation. Often, however, there are smaller areas in which certain shrub types may be found in virtually pure stands. While passing through these areas, one's attention can be focused on the sharpness of the boundaries between the zones occupied by each shrub type and on the great predominance of one or a few species in each type. These ecotonal boundary lines are most noticeable in areas where marked color changes or size differences occur in the adjacent shrub species.

It has been widely suggested that these vegetation communities within the ecotonal lines are an expression of edaphic factors in the environment (Kearney et al., 1914; Clements, 1920; Flowers, 1934; Shantz, 1938; Weaver and Clements, 1938; Shantz and Piemeisal, 1940; Billings, 1945, 1949, 1950, 1952; Fautin, 1946; Mason, 1946; Fireman and Hayward, 1952). More recent work, however, casts some doubt upon the influence of existing soil properties on the vegetation mosaic because distinct patterns of vegetation have not been found to correlate with sharp changes in the physical and chemical properties of soil (Gates et al., 1956; Vest, 1962; Mitchell et al., 1966; Branson et al., 1967).

Artemisia, Eurotia, and Juniperus ecotonal lines are common in the higher elevation areas of the Nevada Test Site. Figure 1 (following page) shows a typical example of one on Pahute Mesa in which Artemisia tridentata and Juniperus osteosperma exist in essentially pure stands on a west-facing bajada sloping gently onto a playa covered with a pure stand of Eurotia lanata. J. osteosperma occupies the upper regions of the bajada and A. tridentata occupies the zone between these two shrub types. The width of the A. tridentata community varies considerably. In some places, however, it exists in narrow bands having sharp ecotonal lines with the adjacent species, as shown in Figure 1. We found this area of particular interest to study because of the sharpness of the ecotones.

An examination of the soil profile along a line transecting these ecotones disclosed some interesting differences in edaphic characteristics between the three-species ecotones. The soil of the Juniperus region is virtually undeveloped at the surface of an outcrop of Paleozoic limestone and dolomite parent material. The hardpan just a few cm below the friable surface material cannot be penetrated easily without a hand pick or heavy digging equipment (Figure 2). The slope is sufficient to permit erosion of fine-textured, weathered materials down-slope during heavy rains. Soil in the Artemisia zone has a well-developed profile with considerable coarse-textured material, as shown in Figure 3. The soil profile is well aerated to depths of at least 1 m before encountering the hard pan or parent material. The soil on the playa occupied by E. lanata is fine-textured to depths greater than 1 m, but there are no indications that it is poorly drained (Figure 4).

Determinations of the profile characteristics and the physical and chemical properties of these soils are in progress. A few preliminary data on particle size analysis and salinity properties appear in Table 1. There are marked differences in the particle-size distribution in the soil profile of these

Figure 1. *Artemisia*, *Eurotia*, and *Juniperus* ecotones on Pahute Mesa at the Nevada Test Site. *E. lanata* is in front with *A. tridentata* next.

Figure 2. Surface soil material overlaying the hardpan outcrop of limestone parent material occupied by J. osteosperma on Pahute Mesa.

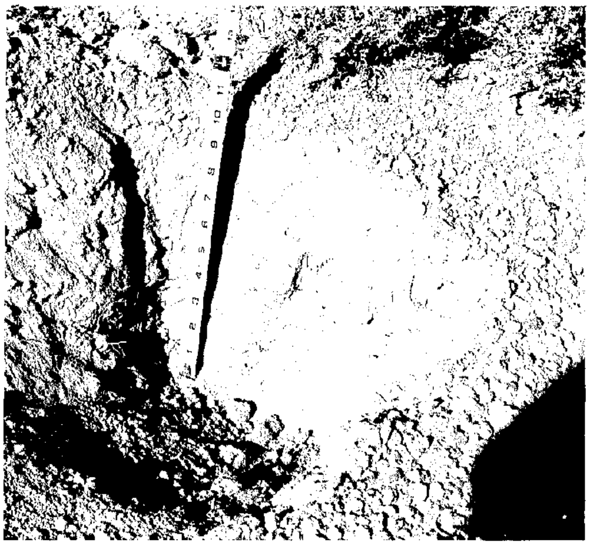


Figure 3. Soil surface material in the zone occupied by a pure stand of A. tridentata. Note the course-textured well aerated nature of this profile.

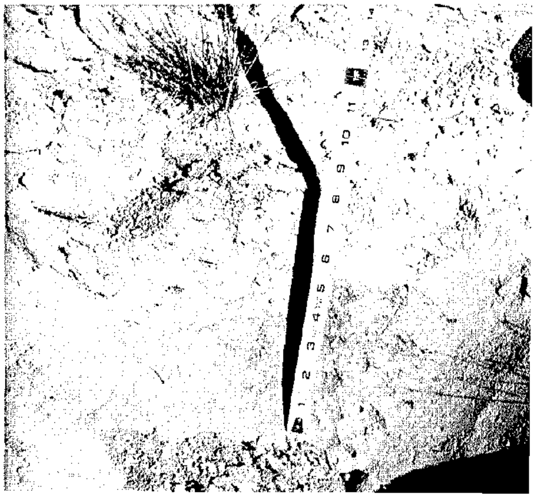


Figure 4. Fine-textured soil surface material of the playa occupied by a pure stand of E. lanata.

Table 1. Preliminary data on particle size distribution and saline properties of soils from the Pahute Mesa ecotone study area.

Ecotone species	Particle size distribution in soil profile								Saturation extract		
	Profile depth	Stones and gravel	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt and clay	pH	EC 25°	Cl$^-$
	cm	>2mm	>.83mm	>.49mm	>.25mm	>.1mm	>.05mm	<.05mm		mmhos/cm	me/l
Juniperus	0-7	48.6	6.2	7.1	13.3	12.9	7.7	4.2	8.20	0.370	
	23-30*	28.3	18.4	10.0	14.8	13.6	6.8	8.1	8.30	0.370	
Artemisia	0-7	9.7	10.1	9.0	16.7	20.5	25.5	8.5	8.45	0.358	0.58
	23-30	8.9	10.6	8.8	16.8	21.1	23.4	10.5	8.55	0.343	0.38
Eurotia	0-7	2.3	0.9	7.4	16.1	13.2	44.7	15.5	8.00	0.995	4.61
	23-30	1.9	6.1	10.5	12.6	15.3	40.9	12.8	8.40	0.537	0.78

*Strongly cemented hard pan material broken up with mortar and pestal.

Table 2. Mineral composition of plant samples taken from the Pahute Mesa ecotonal lines (dry weight basis).

Species	Part	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Ti	Al	Mo	Co	Ni	Sr	Ba
		% of dry weight						ppm of dry weight											
Juniperus osteosperma	Leaf	0.13	0.031	0.49	2.04	0.15	0.42	—	17	525	36	24	90	918	1.3	0.5	70	92	13
Chrysothamnus viscidiflorus	Leaf	0.20	0.035	3.64	1.58	0.28	0.35	12	18	280	69	178	31	490	2.0	0.5	2	63	10
	Stem	0.18	0.037	2.15	1.70	0.16	0.24	4	15	227	54	52	21	467	1.2	0.5	2	75	25
Artemisia tridentata	Leaf	0.17	0.036	1.78	0.89	0.15	0.40	25	14	390	95	37	47	619	0.8	0.5	5	42	25
	Stem	0.13	0.013	2.32	0.60	0.11	0.23	12	14	294	47	21	37	446	1.0	0.5	2	47	19
Eurotia lanata	Leaf	0.20	0.067	3.17	1.46	0.31	0.38	16	33	445	91	105	69	746	1.5	0.5	93	54	17
	Stem	0.19	0.014	2.28	1.26	0.16	0.16	10	24	210	49	24	18	363	0.5	0.5	34	57	9
Oryzopsis hymenoides	Tops	0.16	0.018	1.84	0.64	0.16	0.87	73	78	280	86	41	24	428	9.8	0.5	1	44	29
Sitanion hystrix	Tops	0.18	0.027	1.98	0.69	0.19	1.99	88	64	299	196	28	28	509	15.1	0.5	0.5	40	39

ecotonal areas. The pH is relatively high, but there are no zones of high-salt accumulation in the upper soil profile. There is, however, a trend for higher salt content in the surface material of the playa. In this particular location, the vegetation mosaic correlates very neatly with edaphic factors; the ecotonal lines occur where sharp changes exist in the physical properties of the soil profile. Data are not yet available for correlating chemical properties, but the mineral composition of some plant samples taken from these ecotones (Table 2) does not indicate that marked differences should occur in the chemical properties of these soils. Unfortunately no single shrub species is common to each of these ecotones to serve as an indicator plant. An occasional Chrysothamnus viscidiflorus shrub occurs in the Juniperus region and two grasses, Oryzopsis hymenoides and Sitanion hystrix, are scattered sparsely among the Eurotia without any apparent relationship to the orientation of the ecotonal boundaries.

West (1969) observed that A. tridentata did not grow well on soils derived from dolomitic materials in the White Mountains of California. Kearney et al. (1914) found A. tridentata occurring chiefly on benchlands and on coarse-textured soils with low-salt content in Tooele Valley, Utah. Shantz and Piemeisel (1940) found A. tridentata growing on moderately light-textured soils with low-salt content in Escalante Valley, Utah. E. lanata was growing on soils of fine texture with low-salt content in the upper profile, but often with salts up to 1 per cent at depths below 2 feet. Earlier, Clements (1920) and Weaver and Clements (1938) reported that soils occupied by Artemisia were free from large amounts of salts and were suited for agricultural purposes, unless too shallow. (Those acquainted with the history of the Mormon Pioneers, and their successful agricultural colonization in the intermountain west during the period from 1848 to about 1880, will further appreciate the fertility of soils occupied by A. tridentata.) Weaver and Clements also reported that the occurrence of E. lanata indicated soils that were nonsaline in the first 12 inches, but saline at greater depths.

The question of possible allelopathic effects from toxic substances of one plant on another cannot be ignored; however, the preponderance of cases seen on Pahute Mesa where each of these species grow together in mixed communities would indicate that allelopathic conditions are of little significance in this study area among the three species in question.

Summary

Artemisia, Eurotia, and Juniperus ecotonal lines are prevalent at higher elevations of the Nevada Test Site. Preliminary studies at one area on Pahute Mesa disclosed that the vegetation mosaic correlates very neatly with local edaphic factors in that ecotonal lines occur where sharp changes exist in the physical characteristics of the soil profile. Juniperus occurs on limestone-dolomite outcrops with shallow surface soil and under-lying hard-pan structure. Artemisia occurs on coarse-textured, well-drained soil of low-salt content. Eurotia occurs on fine-textured playa soil with slightly higher salt content.

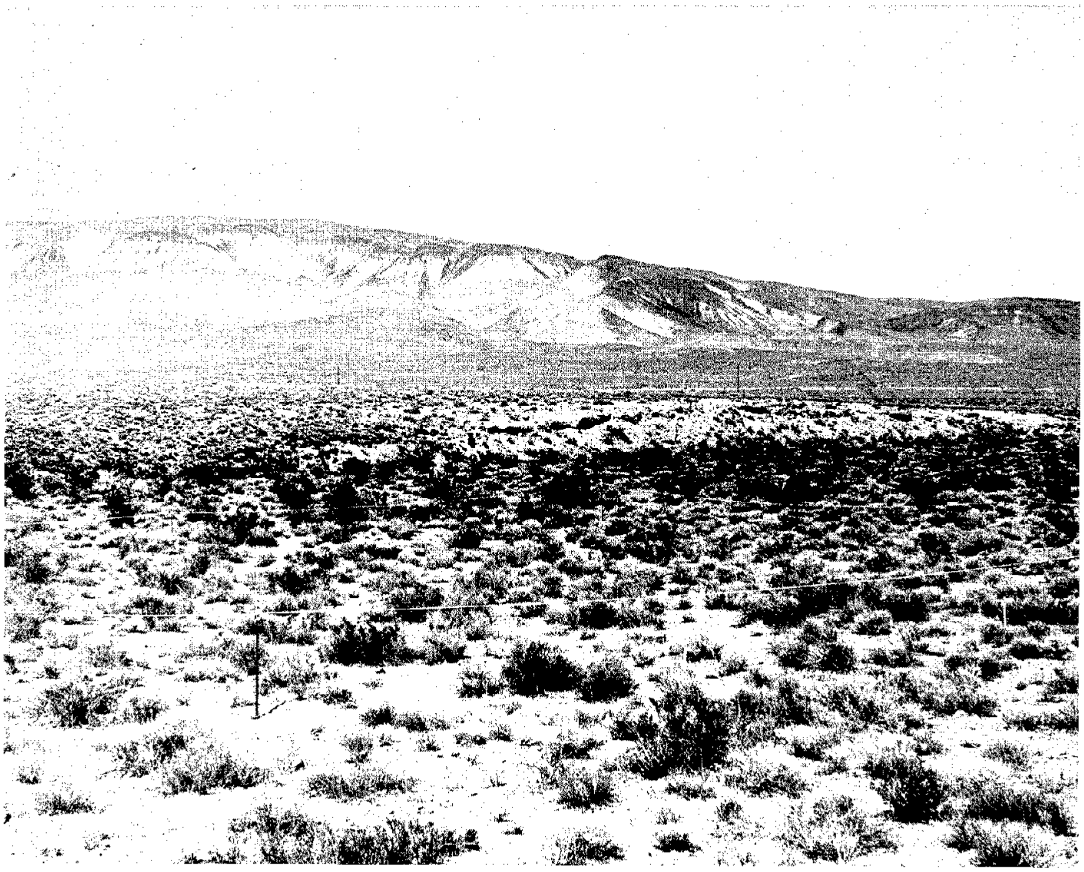
ROOT SYSTEMS OF SOME SHRUBS IN THE SANDY WASH AREA OF ROCK VALLEY

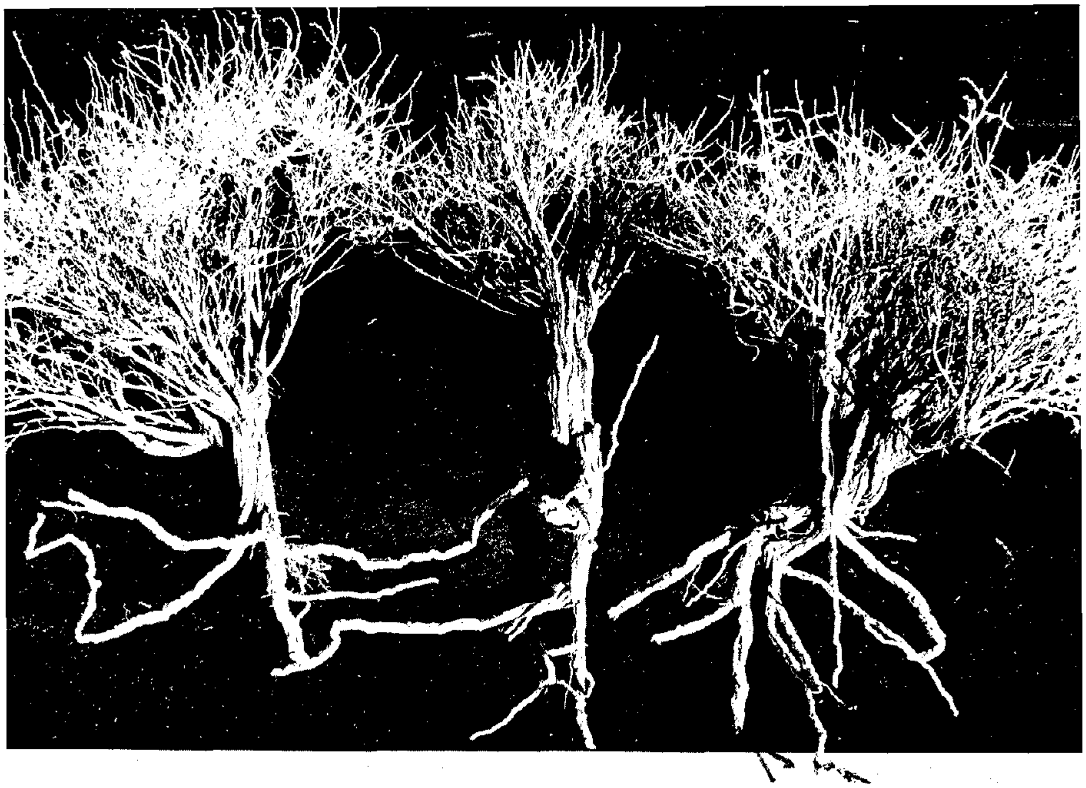
During the summer of 1967, specimens of several different shrub species were excavated in the sandy wash area of Rock Valley in order to determine root and shoot biomass and investigate unique structural patterns which exist among the prominent shrub species. The root habits of desert plants were the subject of an extensive study reported by Cannon in 1911.

The terrain at the excavation site is unlike that of most of Rock Valley which is underlain by caliche hardpan. Figure 1 is a view of the excavation site which also shows an outcropping of the caliche hardpan on the eroded bank of the wash transecting the area. This hardpan layer generally is encountered at depths varying from 10 to 70 cm on the bajadas of the valley and, as one might expect, it markedly influences the distribution and patterning of vegetation.

This site was chosen to facilitate hand tool excavation in order to examine

Figure 1. Root excavation site in the stream bed area of Rock Valley. Note the outcrops of caliche hardpan on the bank of the wash transecting this site.





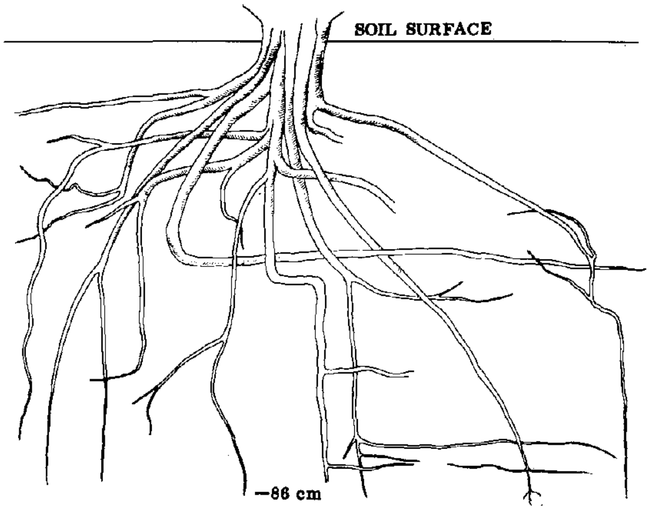
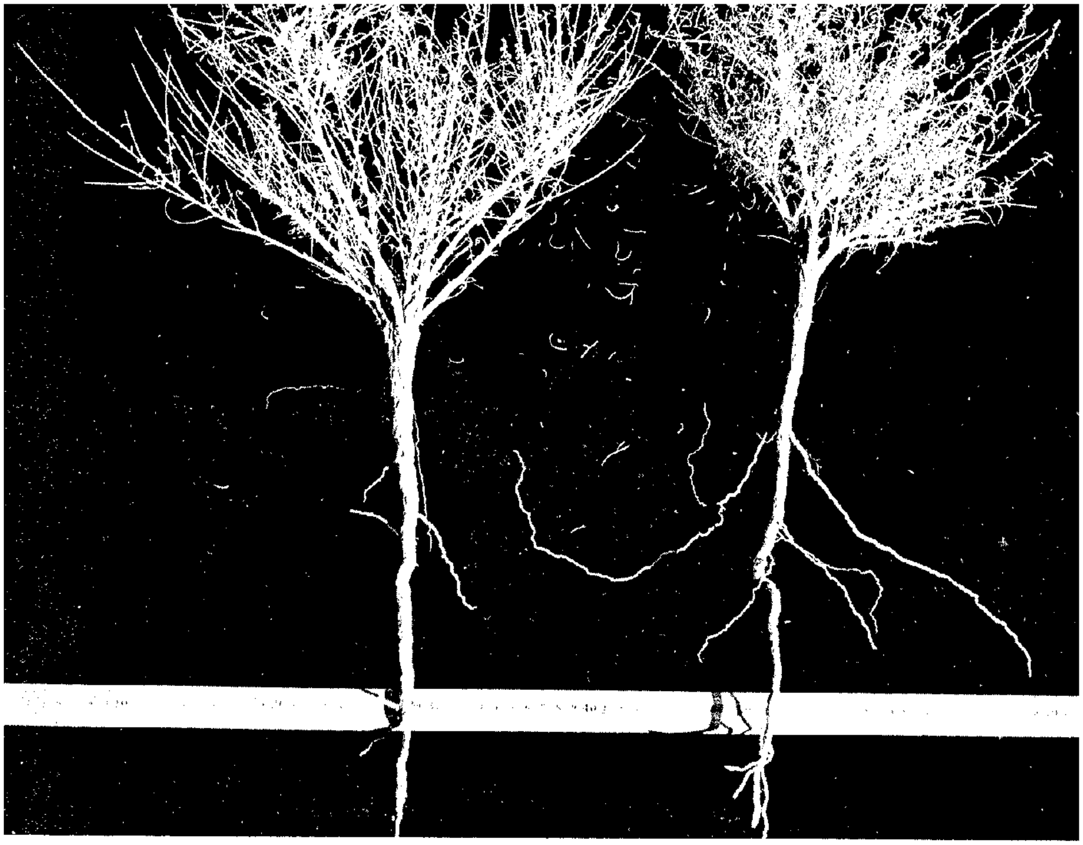


Figure 2. Franseria dumosa, a codominant species in Rock Valley. Notice the massive secondary root system and fractionated root crown structure.

the root structural patterns and recover the roots. While recognizing that the depth of root penetration naturally was deeper than elsewhere in the valley, we decided that the absence of hardpan and the presence of deep, uniform sediments would have permitted root development under more uniform edaphic conditions, thus giving better opportunity for inherent differences in root struc-



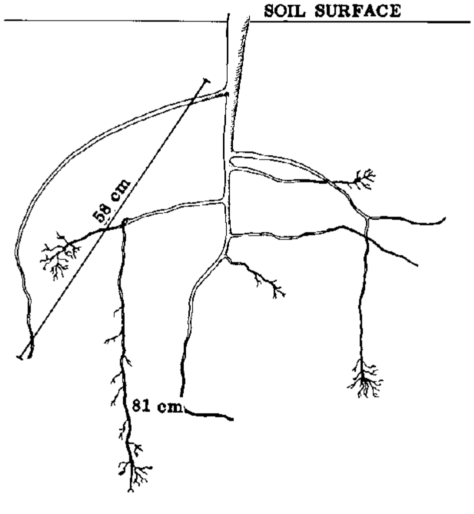
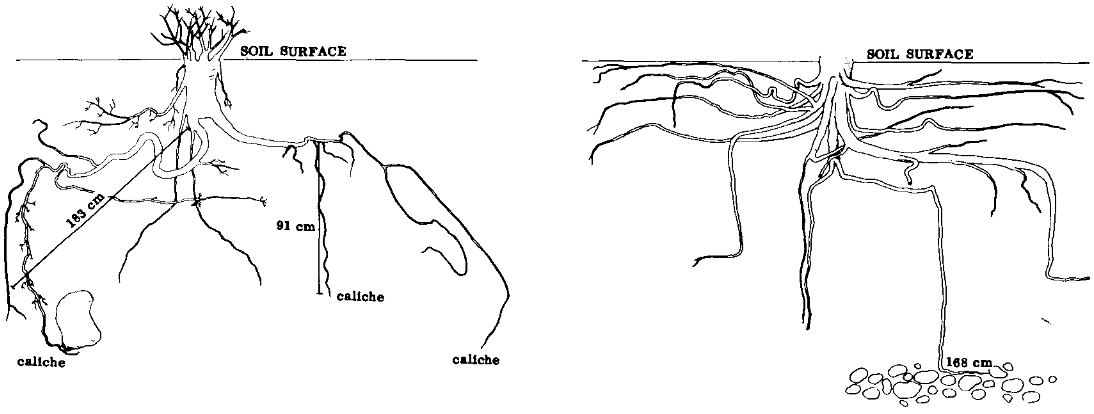


Figure 3. Hymenoclea salsola, a common shrub usually found growing on the unrestricted stream sediments in washes of Rock Valley.

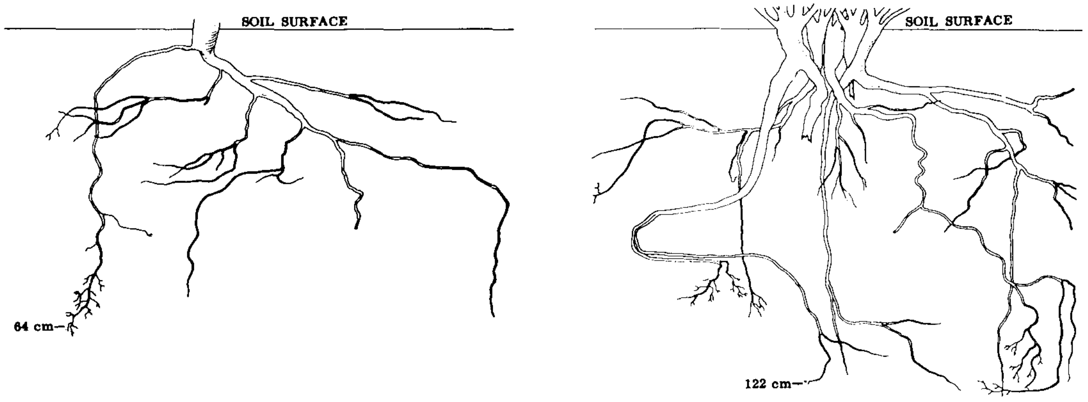
tural patterns to occur.

Figures 2 to 6 are photographs of some partially intact plants accompanied by drawings representing an artist's concept of the gross root systems. One of the most striking characteristics of the root structures of several species excavated was the pronounced absence of small, auxiliary roots. Only in the



Ephedra nevadensis

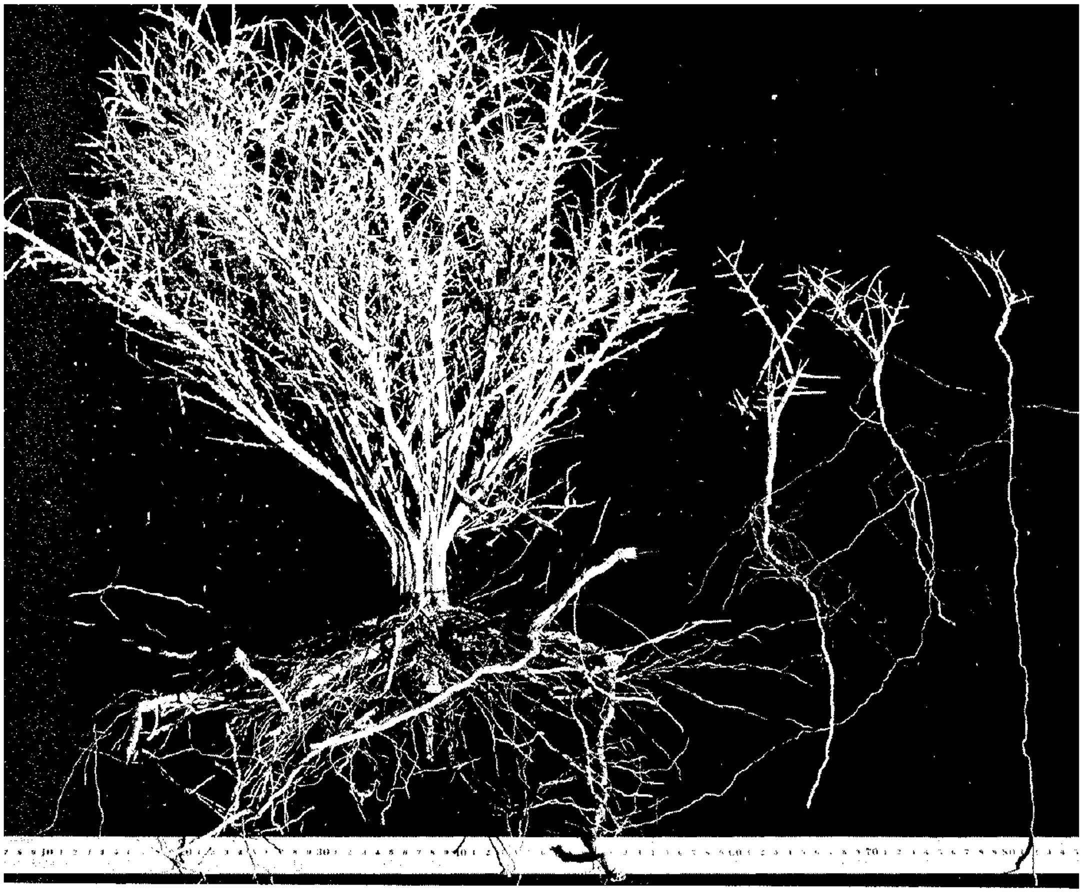
Larrea divaricata



Eurotia lanata

Lycium andersonii

Figure 4. Artist's conception of root systems of shrubs commonly found in the Rock Valley area of the northern Mojave Desert.



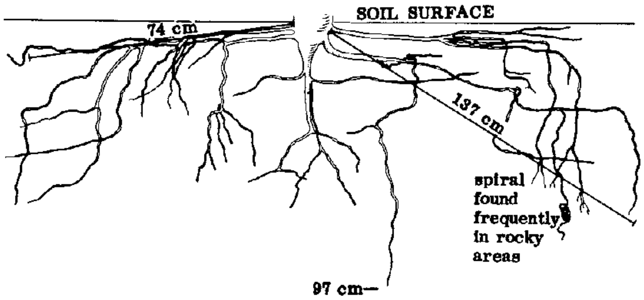
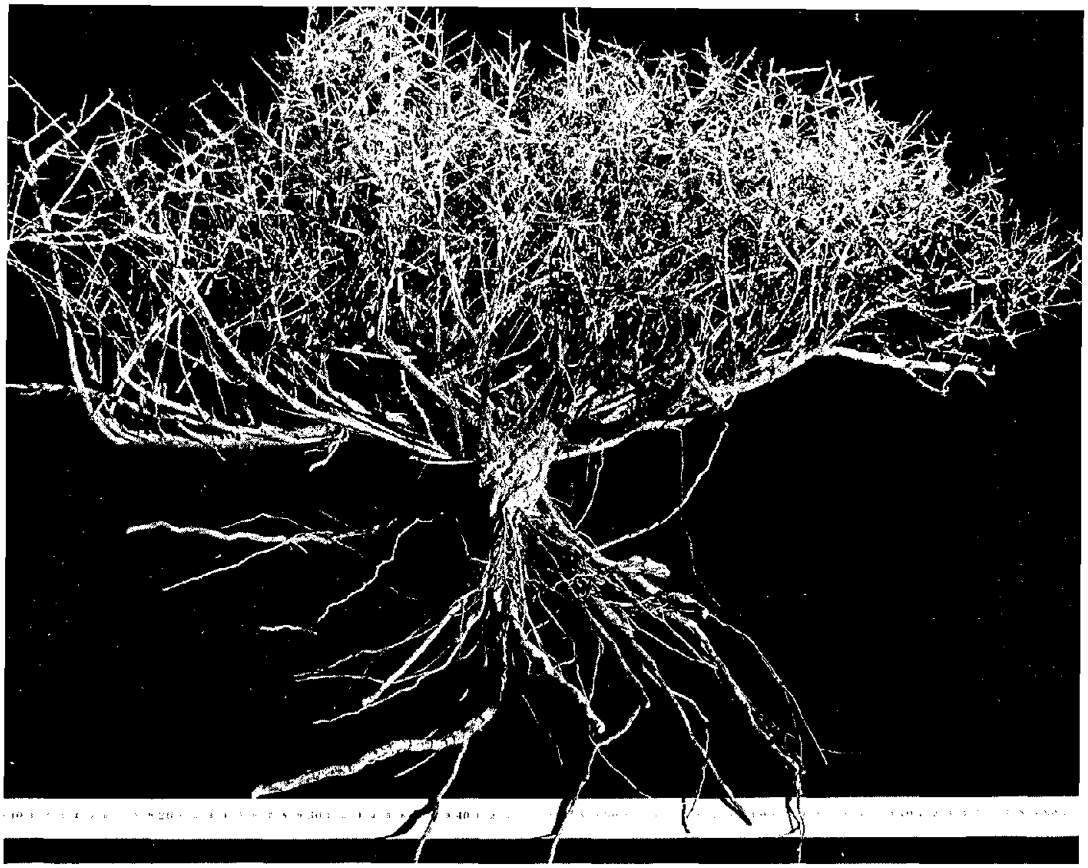


Figure 5. *Grayia spinosa*, commonly found in Rock Valley growing separately and in association with other shrub species. Note the dense filamentous root system.

root systems of young plant specimens and near the tips of large feeder roots did we observe many fine roots. Examples of these root structural systems are shown in Figures 2, 3, and 4. Note the general characteristics of deep tap roots and massive secondary roots which penetrate deeply and laterally. We have made root excavations of these shrub species in hardpan areas and



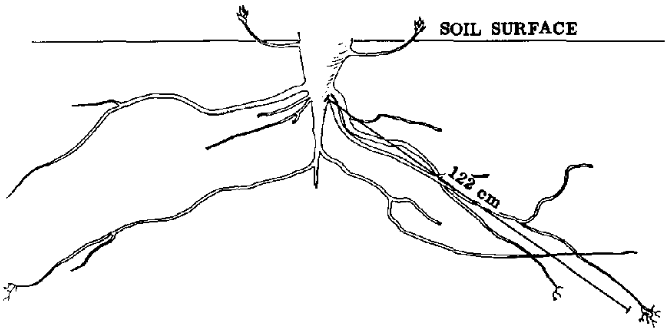


Figure 6. Krameria parvifolia, a filamentous rooted shrub commonly growing in association with other species as an understory plant. It serves as a seed catchment site and protective host plant for numerous winter annuals.

find this same massive structure in mature plants but with more pronounced lateral growth out into the loose sediments above the impervious hardpan. These root structures spread into an area much greater than the canopy cover and, as shown by data in Table 1, may develop greater biomass than the aboveground portion of the shrub.

Table 1. Root and top biomass of shrubs excavated in the Rock Valley wash area.

Shrub species	Shrub dimensions width	height	Root weight	Top weight	Root/top
	cm	cm	g	g	ratio
Acamptopappus shockleyi	30	25	51	54	0.94
Ephedra nevadensis	76	53	440	305	1.44
Eurotia lanata 1	36	36	47	94	0.50
2	30	23	8	15	0.53
Franseria dumosa 1	28	20	19	16	1.19
2	28	18	16	18	0.89
3	61	36	643	168	3.83
4	69	30	405	356	1.14
5	69	30	337	265	1.27
6	69	30	406	246	1.65
Grayia spinosa 1	84	64	360	594	0.61
2	84	66	473	750	0.63
Krameria parvifolia 1	56	13	100	36	2.78
2	46	13	45	27	1.67
Larrea divaricata 1	36	33	53	35	1.51
2	86	66	364	379	0.96
3	183	152	2586	1812	1.43
Lycium andersonii 1	76	33	923	362	2.54
2	58	30	436	300	1.45
Lycium pallidum 1	36	18	64	16	4.00
2	71	48	142	138	1.03

Examples of shrub specimens which show less tendency to develop a massive tap root and secondary root system are shown in Figures 5 and 6. As indicated, Grayia spinosa and Krameria parvifolia generally tend to develop root systems having many small roots and root hairs, irrespective of the presence or absence of underlying caliche hardpan.

Another striking characteristic of these root systems is the presence of numerous old dead roots and an abundance of mycorrhizal fungi associated with both dead and living roots. Went and Stark (1968) have discussed the biological and mechanical role of soil fungi in both tropical and desert soils. We have found considerable evidence to indicate a constant renewing of the root system of old, mature shrubs through new root production initiated at the root crowns. The physiological capabilities of the roots of desert shrubs are intriguing in view of the fact that such massive systems can be supported and renewed under conditions in which the above ground portion of the plant is seemingly dormant for more than half of the year and the roots are subjected to extremes in soil moisture stress for nearly the same periods of time.

We found no uniquely different root structural system among the species examined than seem to occur in shrubs and trees common to temperate climate ecosystems. Specimens of these shrub species grown in artificial conditions in the laboratory and glasshouse or outdoors in temperate or subtropical climatic conditions have not shown unique root characteristics.

Summary

Root excavation studies of specimens of prominent shrub species in Rock Valley disclosed structural systems ranging from massive tap root and secondary root systems to filamentous structured systems. The root biomass often exceeds the above-ground biomass. These root systems penetrate deeply into loose sediments or grow laterally in the loose soil overlaying impervious caliche hardpan layers. Shrubs generally grow much better in soils with unrestricted root penetration; however, since there is usually no close water table in this desert soil, the extent of root development is limited to the depth of the moisture zone from penetrating rainfall. An abundance of mycorrhizal fungi generally is associated with both living and dead roots. Roots of desert shrubs have the unique capacity to survive long periods of dormancy and high moisture stress which appears to be an adaptive mechanism since the same shrub specimens readily thrive when cultured under temperate and semi-tropical conditions.

SEED GERMINATION OF SOME NORTHERN MOJAVE AND SOUTHERN GREAT BASIN PLANT SPECIES

We have been desirous of growing populations of desert plants both from seeds and from vegetative propagation for experimental studies. This report describes successes and failures for plant species from the Nevada Test Site. Our purpose was not to explore optimum conditions for germination, but rather to find conditions under which plants can be germinated for use in other studies.

Reports from the literature which indicate germination conditions under difficult circumstances are as follows:

Amen (1963) has reviewed the question of seed dormancy and lists seasonal changes in red and far red light, microbial activity, seasonal fluctuations in precipitation which remove inhibitors, and extreme fluctuations in temperature as factors which can terminate dormancy.

Quick and Quick (1961) reported abundant seedling regeneration of Ceanothus after fire. Most Ceanothus seeds will not imbibe water in the laboratory unless they are first subjected to some type of heat treatment.

Germination of four tree species from the Sonoran Desert were studied by Poole (1958). Two required H_2SO_4 treatments. Temperature ranges for optimum germination varied from 21 - 30°C for one species to 13 - 20°C for another. A temperature of 71°C improved germination in one species by breaking dormancy.

Muhktar (1961) reported that scarification of four grasses and two woody plant seeds from the Sonoran Desert increased germination in all cases.

Shellhorn (1955) reported that Larrea divaricata seed germinated at 37°C.

Went and Westergaard (1949) found that L. divaricata germinated in Death Valley following rains at 15 - 16°C but not at 8 - 10°C. Dalton (1962) found that optimum temperature for L. divaricata germination was 35°C. West (1969) reported that salt inclusions had to be leached from Atriplex confertifolia seed before they would germinate.

Mooring et al. (1971) reported that some salt-marsh plant seeds cannot survive drying.

Brunner (Bureau of Land Management, personal communication) says that L. divaricata seed germinate best at pH 6. Artemisia spinescens seed planted in the glasshouse in March 1969 took about 6 months to produce seedlings.

The effect of soil moisture on germination of Salsola pestifera has been briefly tested in comparison with some of the plant species including some agricultural crops (Table 1). Seeds were planted in krilium-treated Yolo loam soil and placed in an incubator of 29°C. Water was added to the different containers to give soil moisture of 5, 6, 7, 8, 9, 10, 11%. The air dry soil contained about 2% soil moisture. The 20 bar level was about 4% soil moisture. The 11% soil moisture was about 1.0 bar. The results after 8 days indicated that barley, corn, buckwheat, and bush beans germinated at lower soil moisture levels than did S. pestifera but that S. pestifera germinated at soil moisture levels lower than Franseria dumosa, Atriplex canescens, or Grayia spinosa (these did not germinate at 11% soil moisture).

Table 1. Effect of soil moisture levels on germination of Salsola.

% soil moisture	Germination characteristics
5	No germination
6	Light germination barley, corn, buckwheat, bush beans
7	Light germination barley, corn, buckwheat, bush beans
8	Germination of S. pestifera, barley, buckwheat, bush beans, sunflower, corn
9	Same as at 8%
10	Same as at 8%
11	Same as at 8%

F. dumosa, A. canescens, and G. spinosa did not germinate in any of the treatments but they do with higher per cent soil moisture.

The following species seem to present no special germination problems if viable seed can be obtained:

Larrea divaricata
Grayia spinosa
Franseria dumosa
Lycium andersonii
Lycium pallidum
Atriplex polycarpa
Yucca brevifolia
Yucca schidigera
Salsola pestifera
Bromus rubens
Sarcobatus vermiculatus
Allenrolfea occidentalis
Hilaria rigida
Muhlenbergia porteri
Artemisia tridentata
Baileya multiradiata
Chrysothamnus nauseosus
Dyssodia cooperi
Stephanomeria pauciflora
Thamnosma montana
Nicotiana trigonophylla
Sporobolus flexuosus
Oenothera megalantha

Species with difficulty in germination (low percentage or variability in lots) are as follows:

Krameria parvifolia—two seeds germinated out of four collections.

Oryzopsis hymenoides—seed will not germinate unless treated for 20 minutes with 70% sulfuric acid.

Juniperus osteosperma—no seed germinated out of several collections. They seem to have no embryos, hence were not viable.

Coleogyne ramosissima, Cercocarpus ledifolius, Cowania mexicana, and Purshia tridentata were germinated from seed. All four respond to a period of moist storage at 5°C. They will in fact germinate at this temperature.

Ephedra nevadensis—1 lot purchased, about 5% germination.

Ephedra viridis—No viable seed obtained.

Sporobolus airoides—1 collection, good germination.

Atriplex canescens—1 collection, no germination.
5 collections, good germination.
4 collections, fair germination.
2 collections, poor germination.

Atriplex hymenelytra—1 collection, no germination.
1 lot purchased, about 10% germination.

Atriplex confertifolia—5 collections, very poor germination.
7 collections, no germination.

Atriplex lentiformis—1 collection, good germination.

Atriplex linearis—1 collection, poor germination.

Atriplex griffithsii—1 collection, good germination.

Eurotia lanata—1 collection, good germination.
1 collection, fair germination.
2 collections, no germination.

Grayia spinosa—1 collection, no germination.
1 collection, very poor germination.

Artemisia tridentata—3 collections, good germination.

Baileya multiradiata—1 collection, fair germination.
1 collection, poor germination.

Chrysothamnus nauseosus—1 collection, good germination.

Encelia virginensis—1 collection, fair germination.

Franseria dumosa—3 collections, fair germination.
3 collections, no germination.
2 collections, poor germination.
3 collections, (glasshouse) poor germination.

Machaeranthera tortifolia—1 collection, fair germination.

Stephanomeria exigua—2 collections, fair germination.

Tetradymia species—2 collections, no germination.

Astragalus species—1 collection, good germination.

Oenothera megalantha—1 collection, fair germination.
1 collection, (glasshouse) poor germination.

Cercocarpus ledifolius—1 collection, fair germination.

Purshia tridentata—1 collection, fair germination.

Lycium pallidum—2 collections, very poor germination.

Nicotiana trygonophylla—1 collection, good germination.

Larrea divaricata—2 collections, poor germination.
1 collection, good germination.

Thamnosma montana—1 collection, fair germination. Seed not readily available.

Most of the collections were obtained from Dr. Janice Beatley. She had tested them and found germination to run from 0% up to about 60%. We did not use any of the lots she found low in germination.

Summary

Seeds of approximately 50 plant species from the Nevada Test Site have been successfully germinated. Populations of most have been prepared for experimental study. In general very little precaution is necessary. Greatest problems are variability in seed collections and low percentages of germination. In some years viability is low and in some of these cases it is related to insect injury of seed. Special seed treatment is necessary in the cases of *Oryzopsis hymenoides* (sulfuric acid scarification) and *Coleogyne ramosissima*, *Cowania mexicana*, *Purshia tridentata*, and *Cercocarpus ledifolius* (chilling needed).

We found evidence of seed dormancy for four or five species but some species failed to germinate and as yet we do not know the reasons or whether or not there is need for leaching of inhibitors from seeds before germination would occur. Our methods of irrigation, however, may automatically do this. Our studies have not been designed to test conditions for germination, but merely to successfully germinate seed for other studies.

PHENOLOGY OF SOME NORTHERN MOJAVE DESERT PLANTS AT LOWER ELEVATIONS OF THE NEVADA TEST SITE

It is generally believed that plant responses are seldom identical for two consecutive years at the Nevada Test Site. Beatley (1969) has accumulated large amounts of data which support this hypothesis. Important environmental factors which regulate growth and development of desert vegetation include the distribution of rainfall and the soil and air temperatures preceding and during a seasonal growth period. Wind and solar radiation appear to be less influential than rainfall and temperature on plant growth in the northern Mojave Desert.

In conjunction with our radiological effects assessment program, a number of study sites were established to monitor environmental factors and document seasonal changes in native vegetation. See page 1 for a map of site locations. Reported herein are data primarily representing the lower elevation areas of Rock Valley, Mercury Valley, and Frenchman Flat.

Materials and Methods

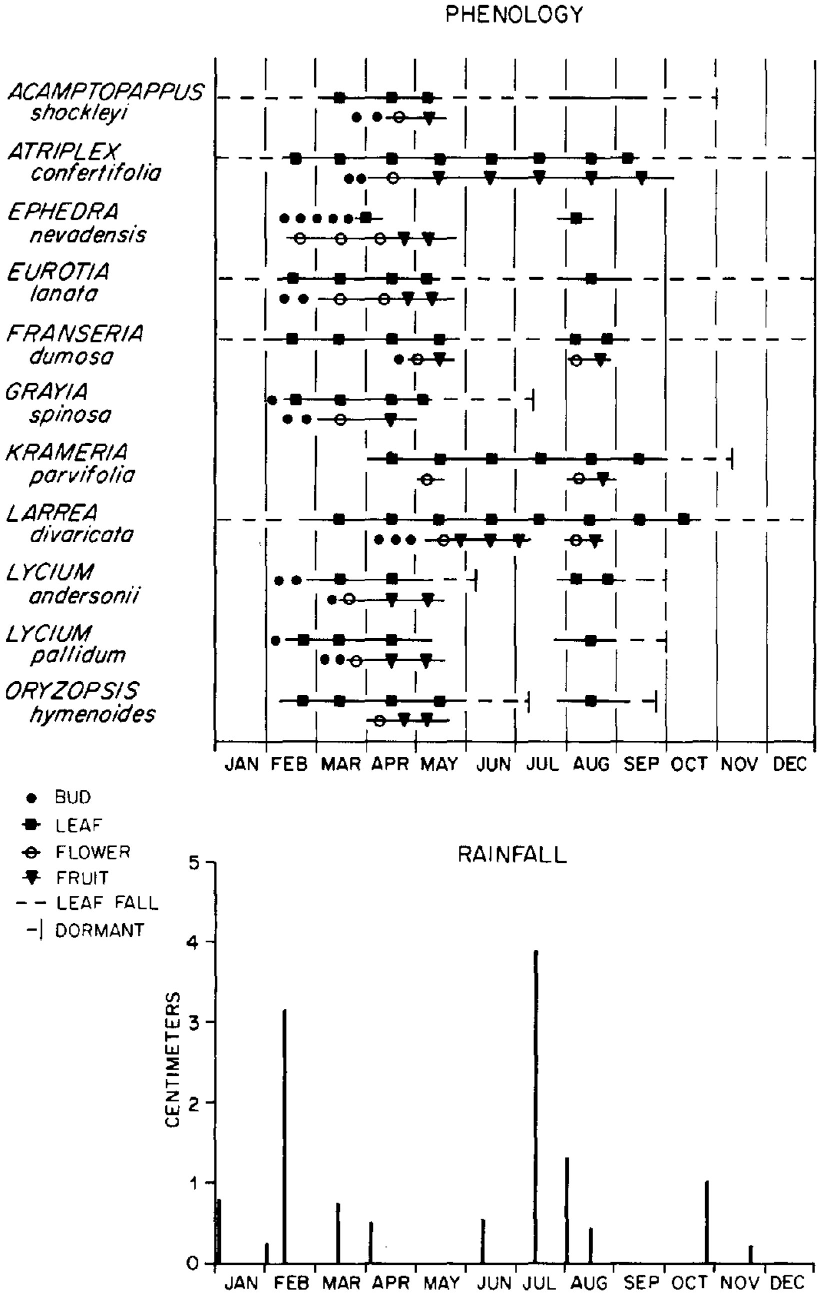
Phenological and environmental measurements were made at two-week intervals during the dormancy period and at weekly intervals during periods of active growth. Additional assessments were made following adventitious rainfall during late summer months. The information recorded on some 27 different shrub species included the status of leaf bud, leaf growth, flower bud, flowering, fruiting, leaf fall, and dormancy.

Environmental data were recorded for the maximum and minimum temperatures (30 cm above ground) and the amount of precipitation since the previous recording period. Soil temperature measurements were taken at depths of 15, 30, and 45 cm using emplaced Fenwal KA31L4 thermistors. Soil temperatures also were taken at 7.5, 23, and 38 cm depths at the Mercury Valley study site. Soil moisture was measured gravimetrically on samples taken at monthly intervals from 7 to 15 cm and 30 to 38 cm depths. Thermocouple psychrometers were emplaced in 1970 for continued soil moisture measurements.

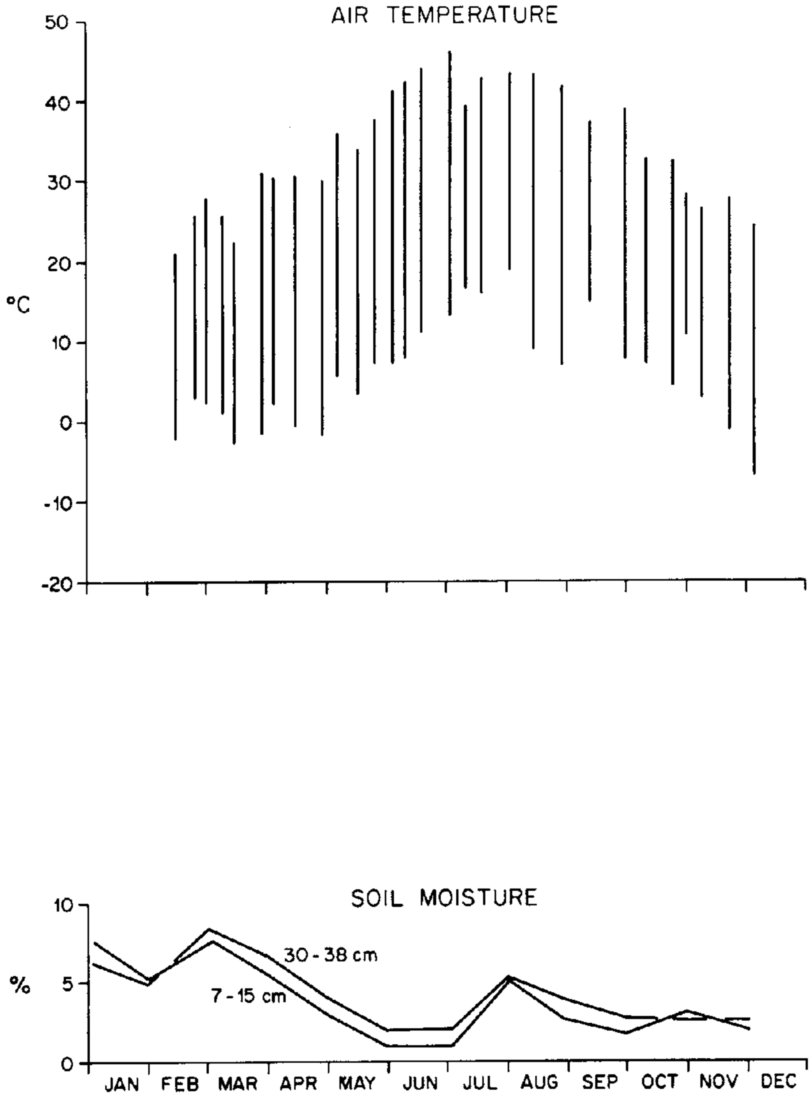
Results and Discussion

Results for 1968 to 1970 for each site are graphically illustrated in the accompanying diagrams so as to give a visual comparison of phenology with rainfall, air temperature, soil temperature, and soil moisture. Space was insufficient to include all recorded data; the emphasis here is on those species common to Rock Valley, Mercury Valley, and Frenchman Flat. Elevations of these sites are 1030, 1100, and 975 m (MSL), respectively.

Plant responses documented during the three years were extremely interesting. One can note, for example, the early responses of such species as _Acamptopappus_ _shockleyi_ and _Sphaeralcea_ _ambigua_ to the warmer than usual spring months of 1968 in Frenchman Flat. In contrast the cold spring of 1969, accompanied by abnormally high rainfall, shifted the active growth period one to two months later in the year. The 1969 growth season was unique in favorable plant response to abnormally high spring rainfall; new photosynthetic productivity varied from four to as much as ten times the normal productivity for most shrub species. Another striking response was the breaking of summer dormancy by several species following the late summer rains in Rock Valley



ROCK VALLEY 1968



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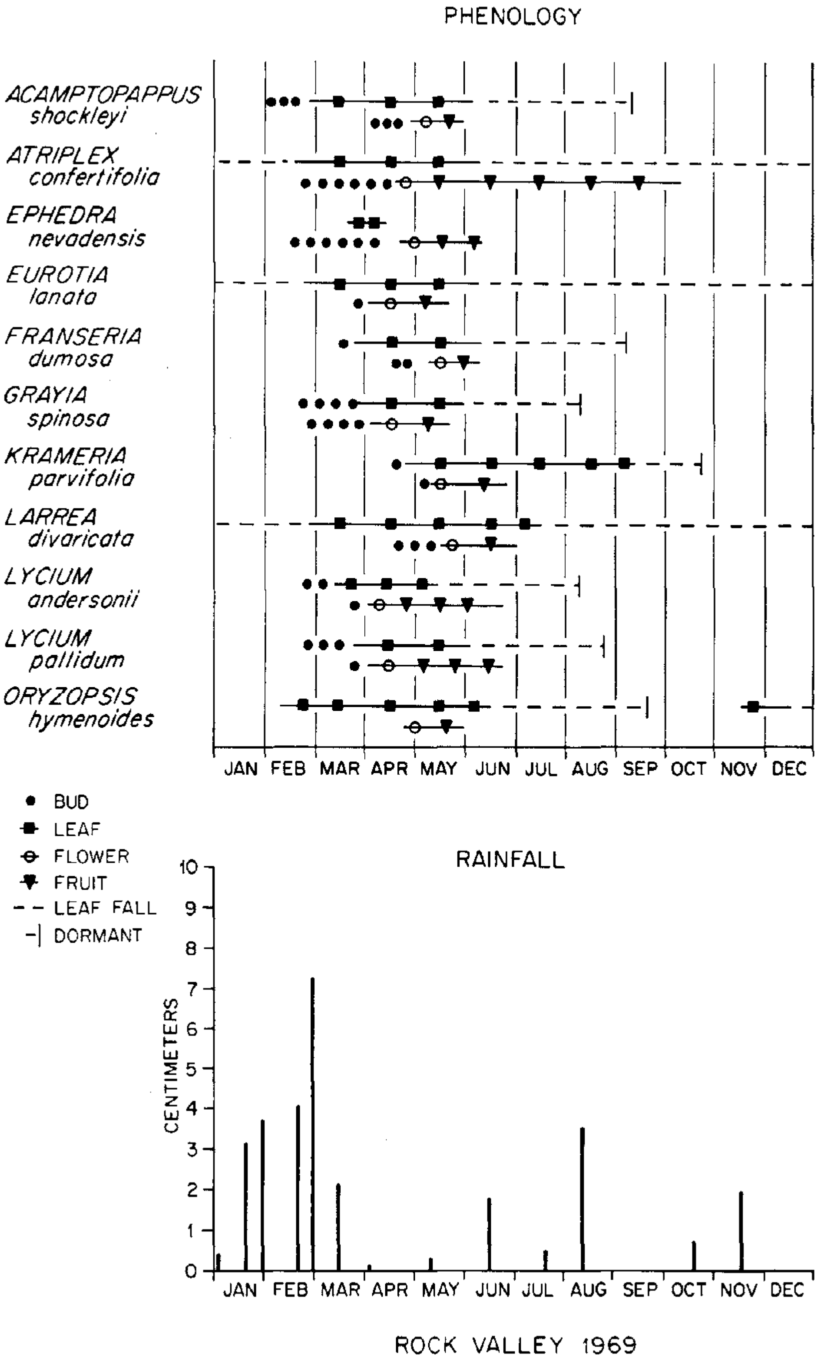
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ATRIPLEX confertifolia
EPHEDRA nevadensis
EUROTIA lanata
FRANSERIA dumosa
GRAYIA spinosa
KRAMERIA parvifolia
LARREA divaricata
LYCIUM andersonii
LYCIUM pallidum
ORYZOPSIS hymenoides
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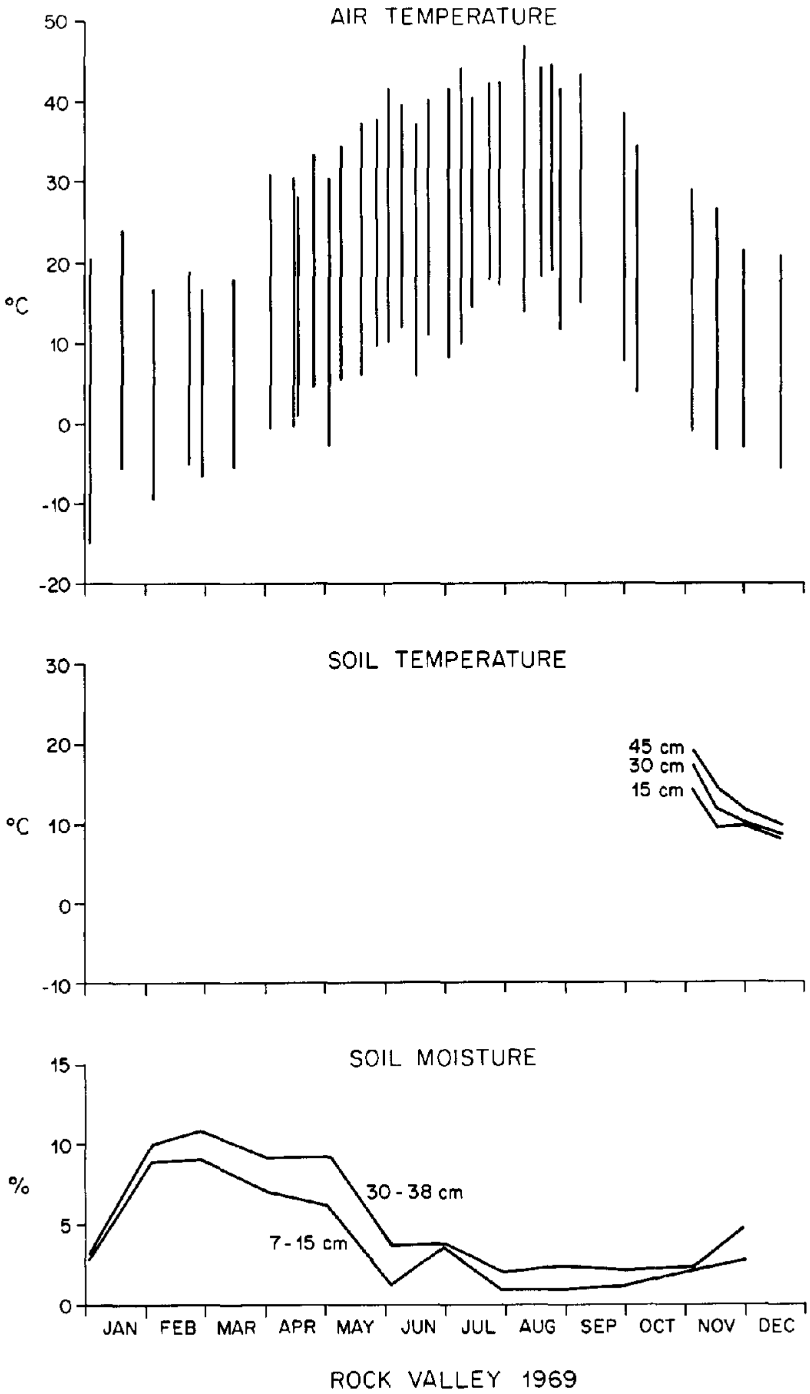
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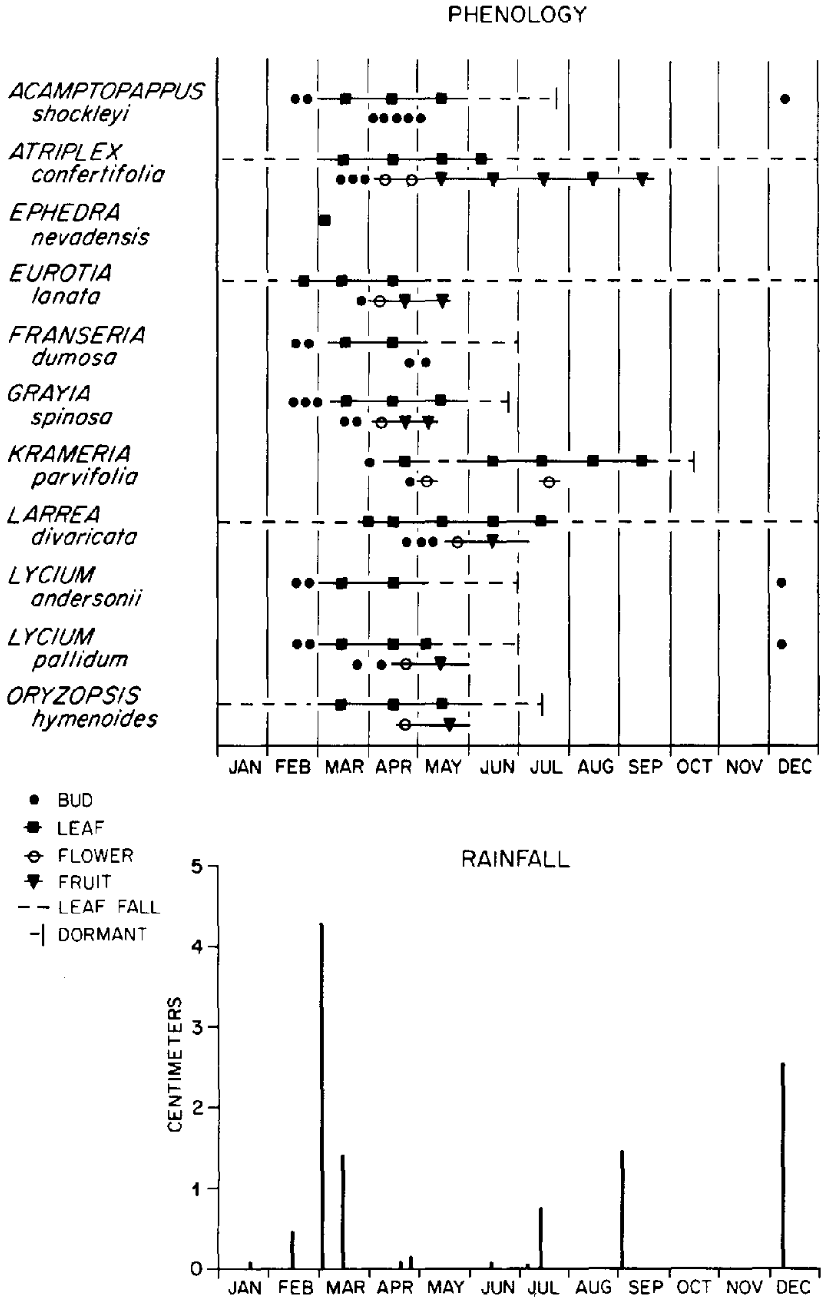

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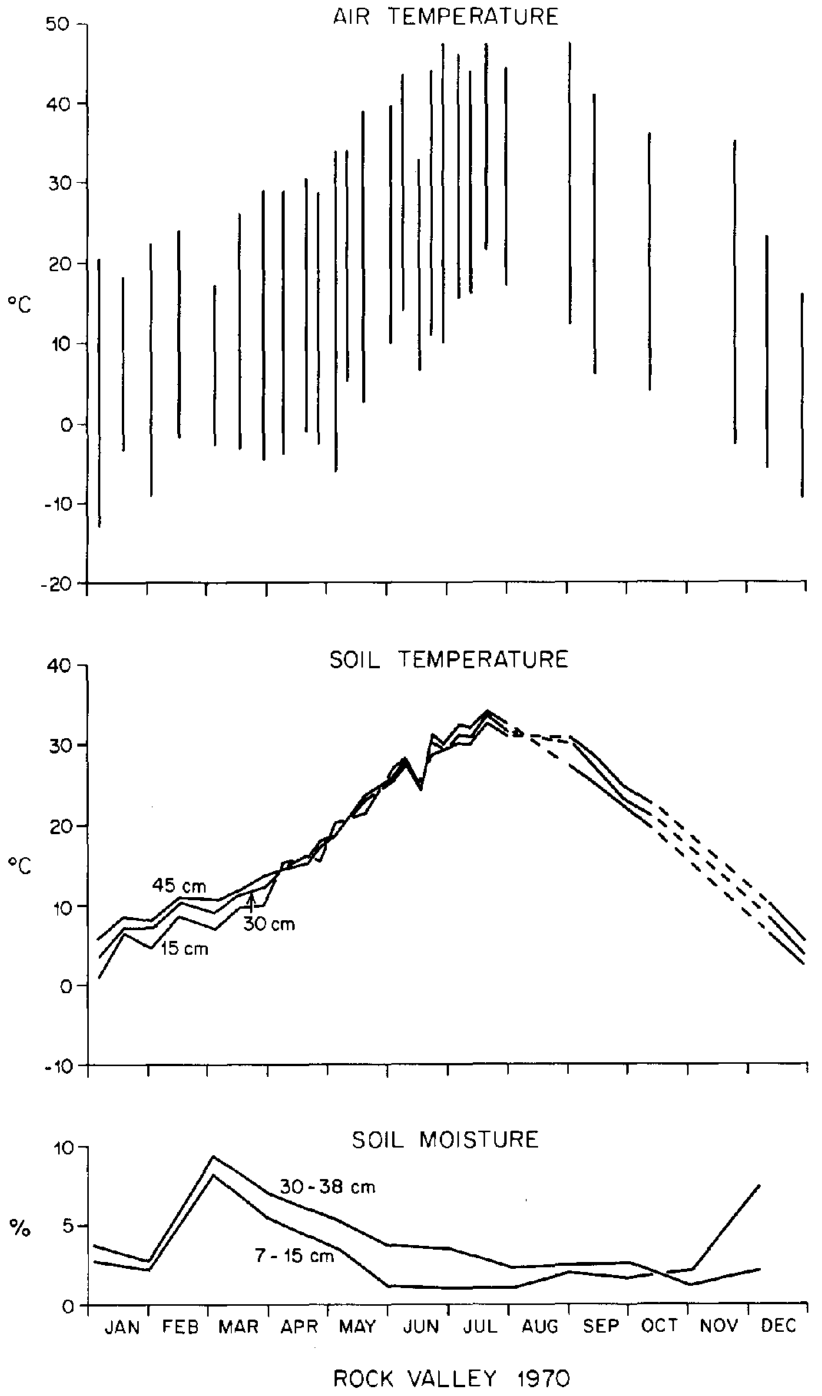
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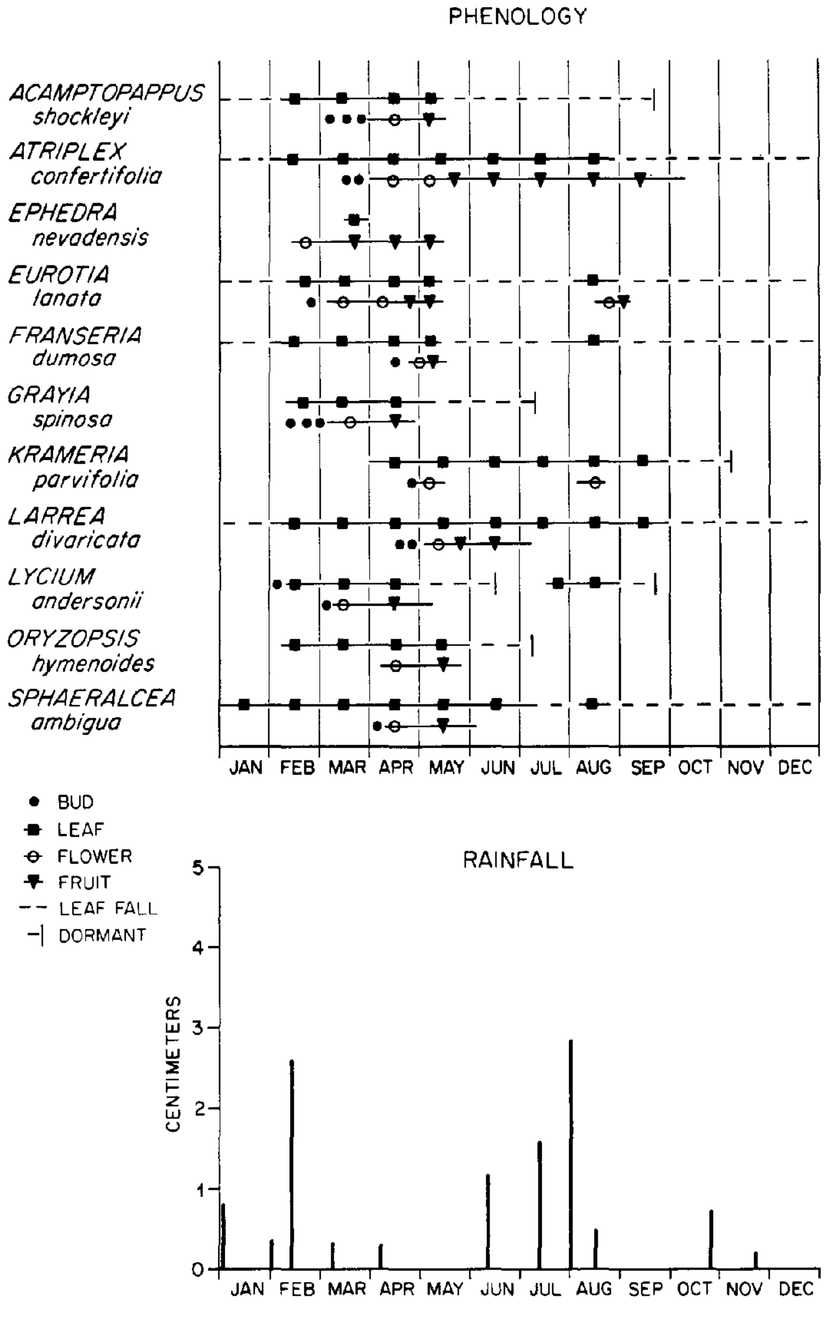

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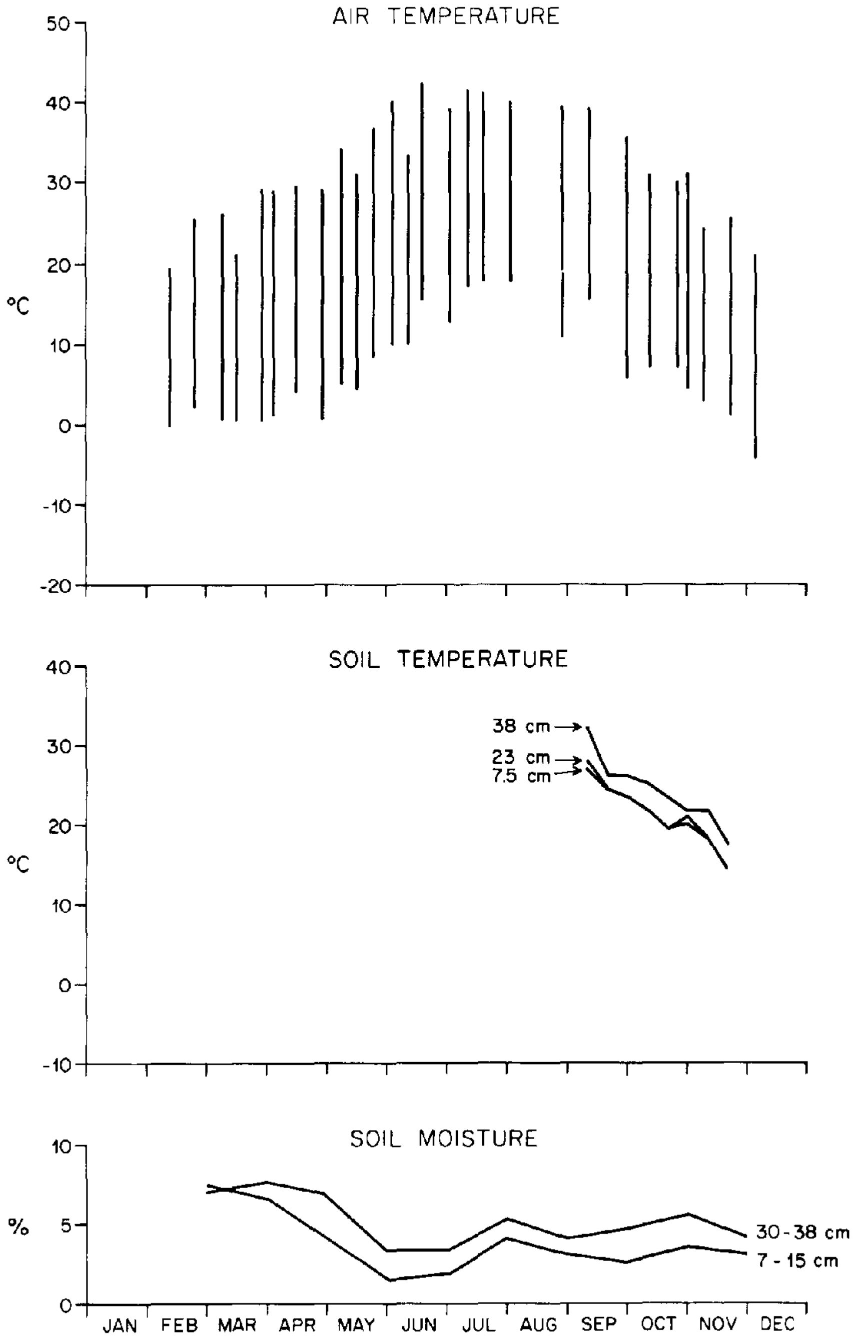

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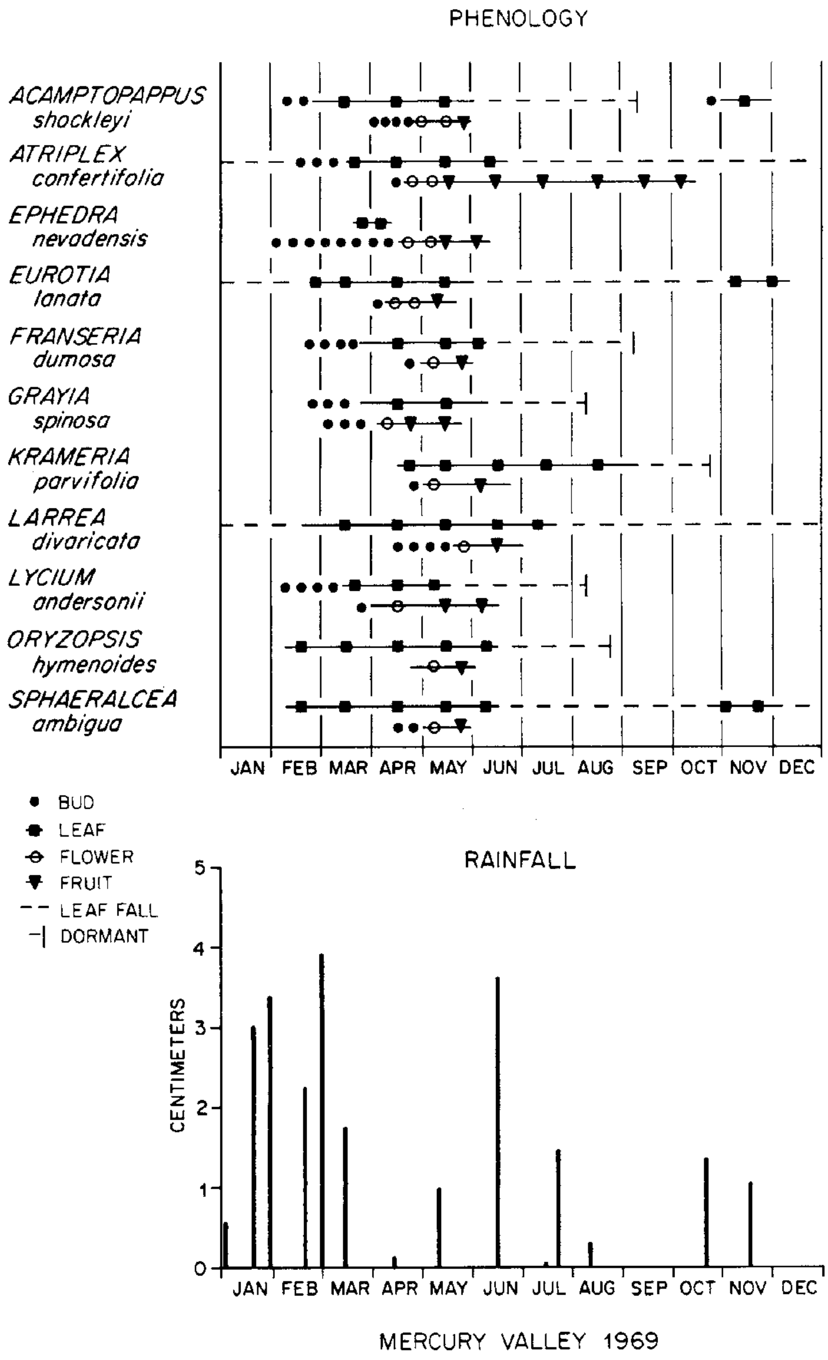
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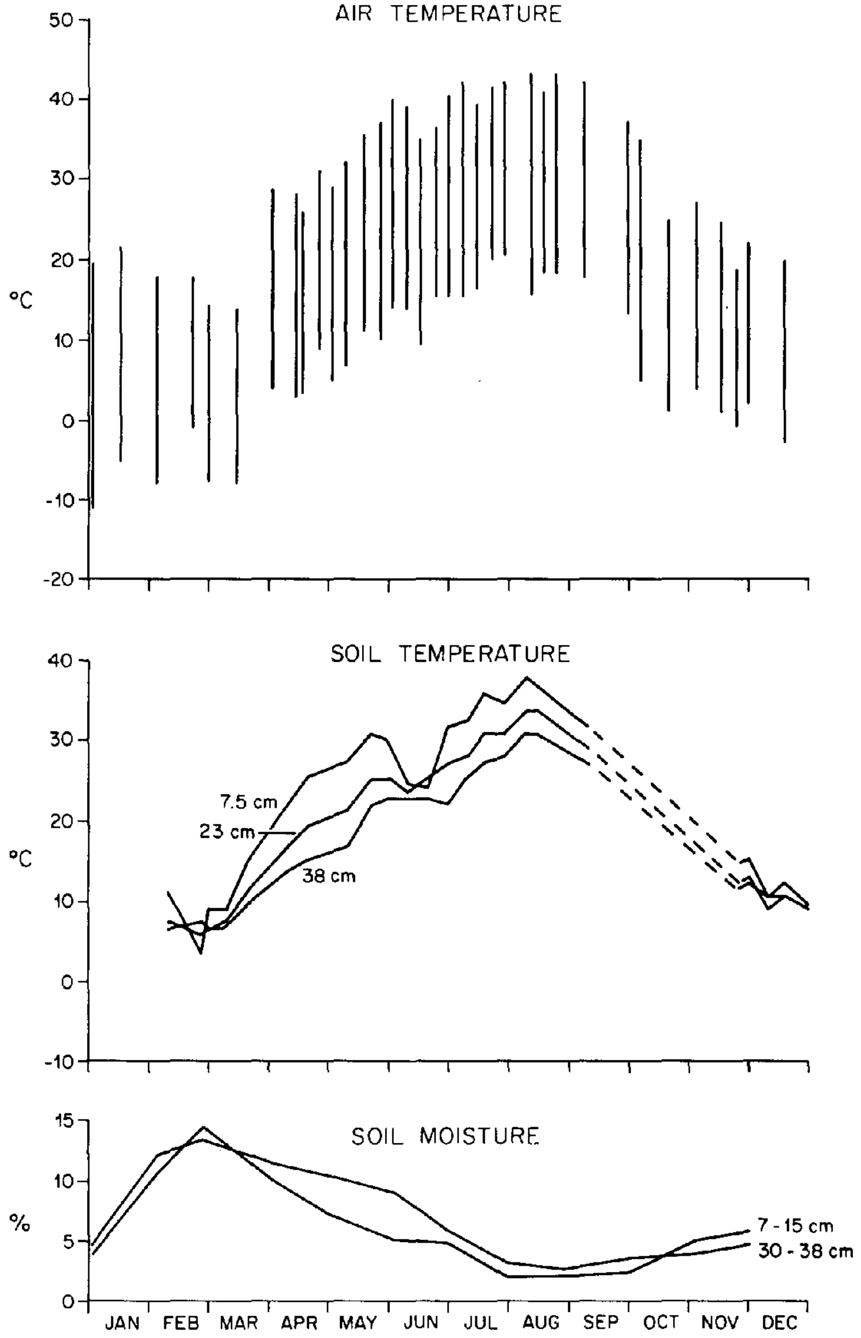

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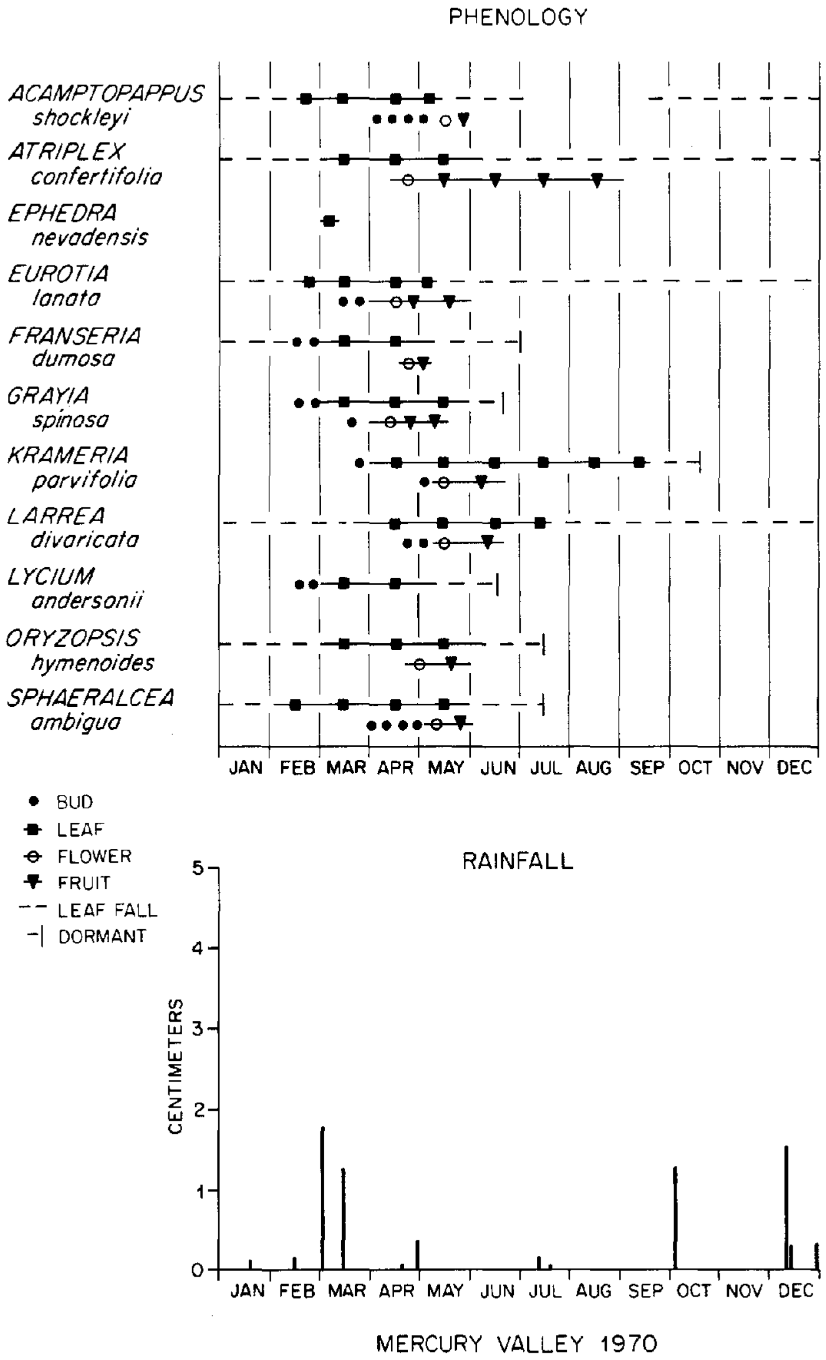
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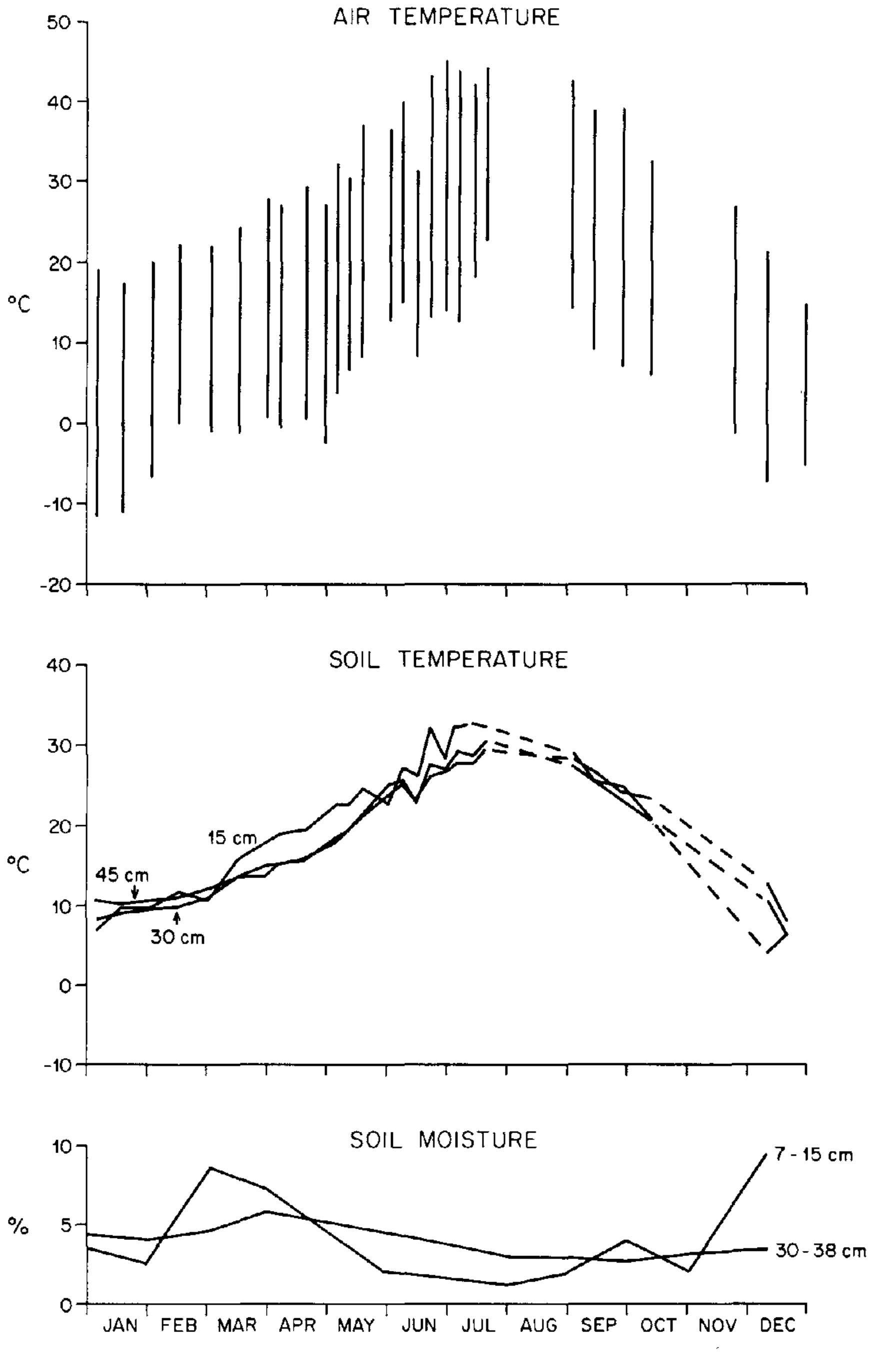

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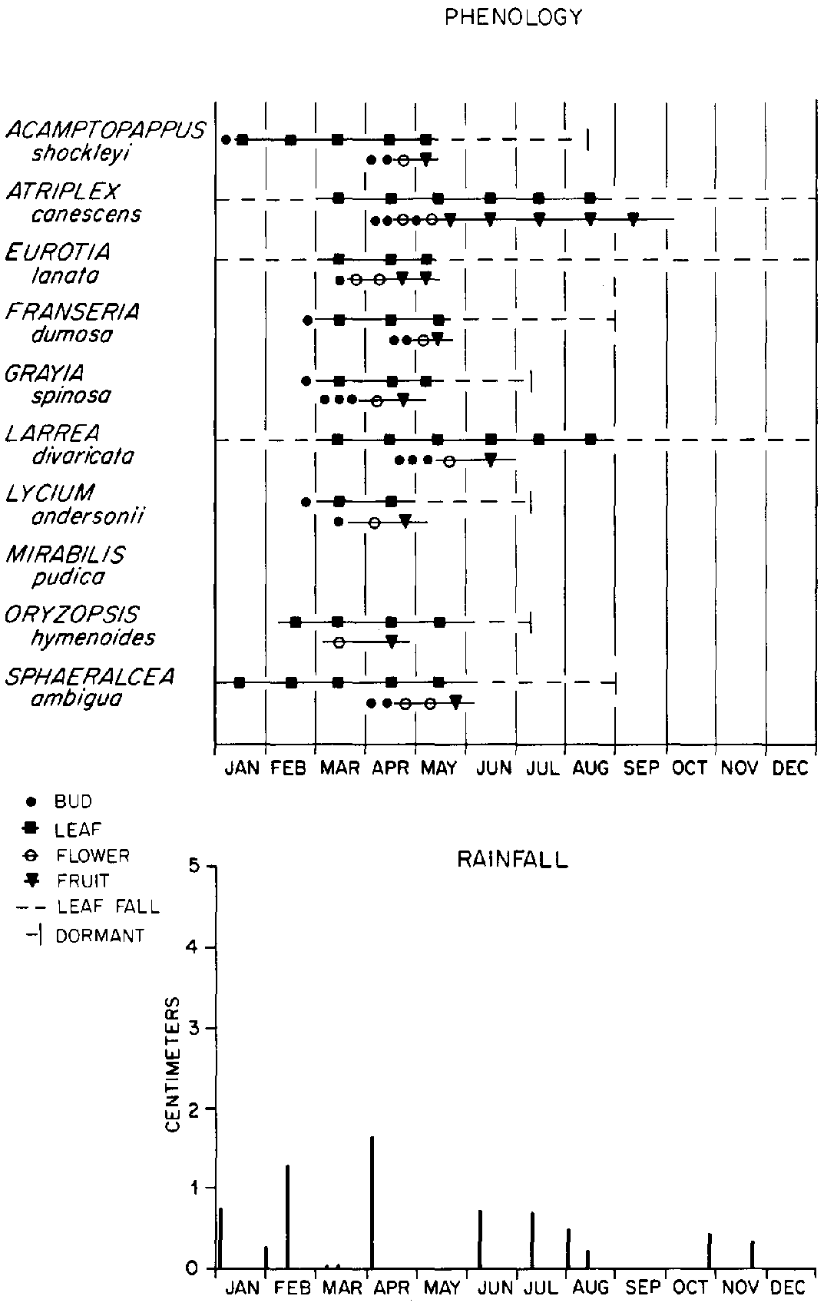
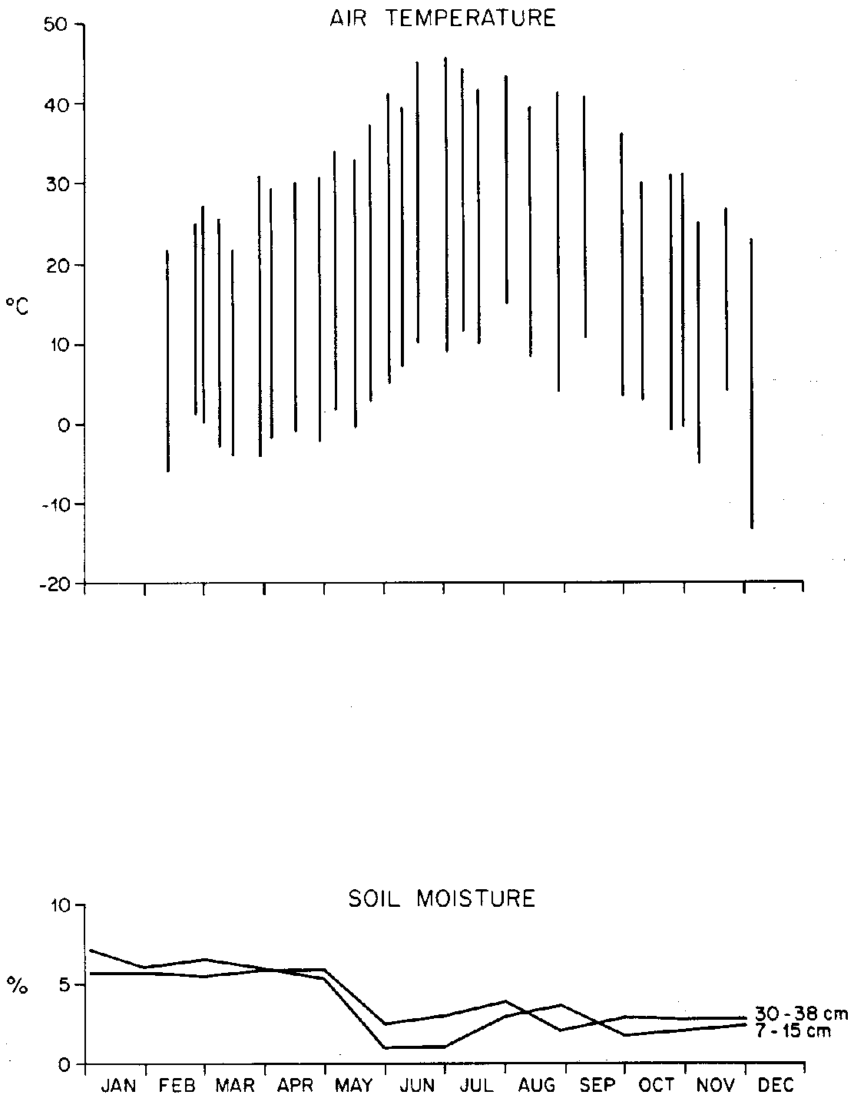


FRENCHMAN FLAT 1968



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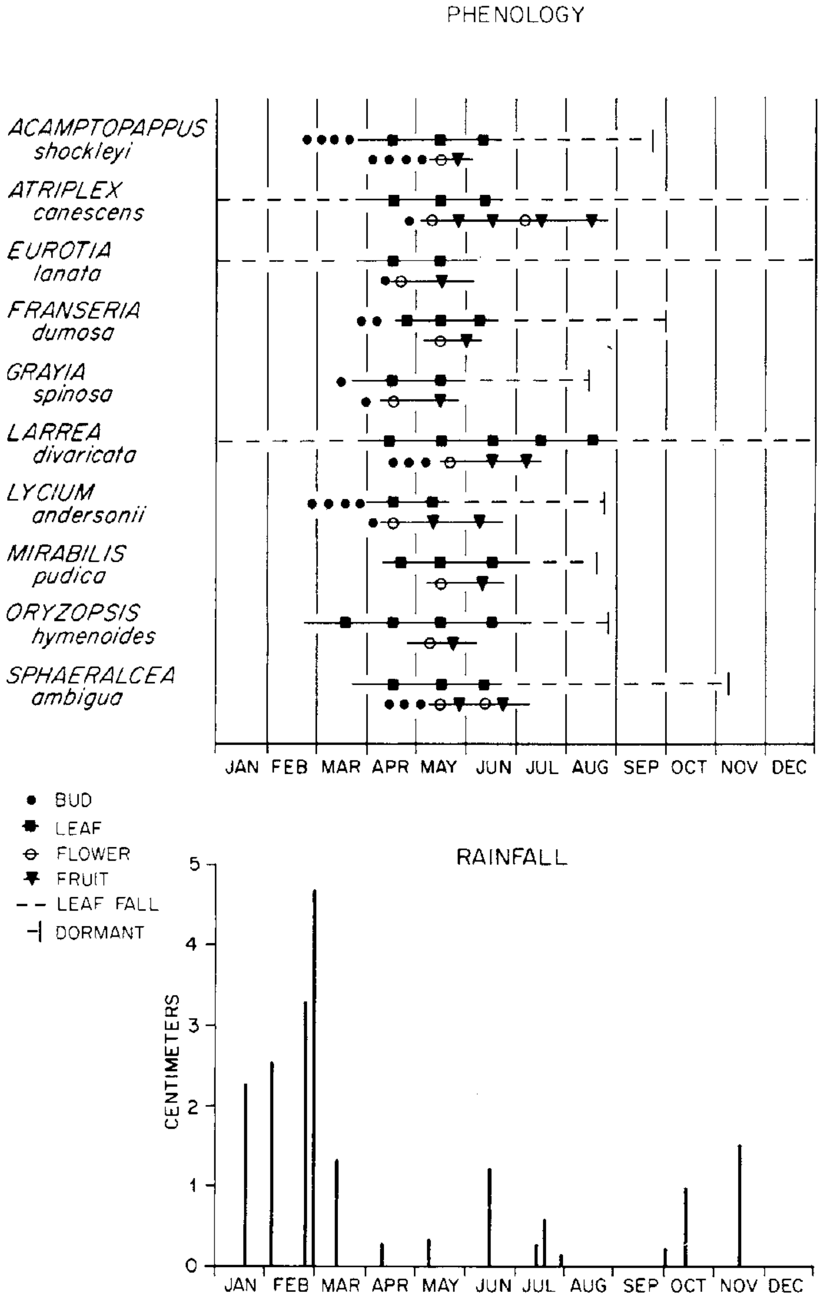

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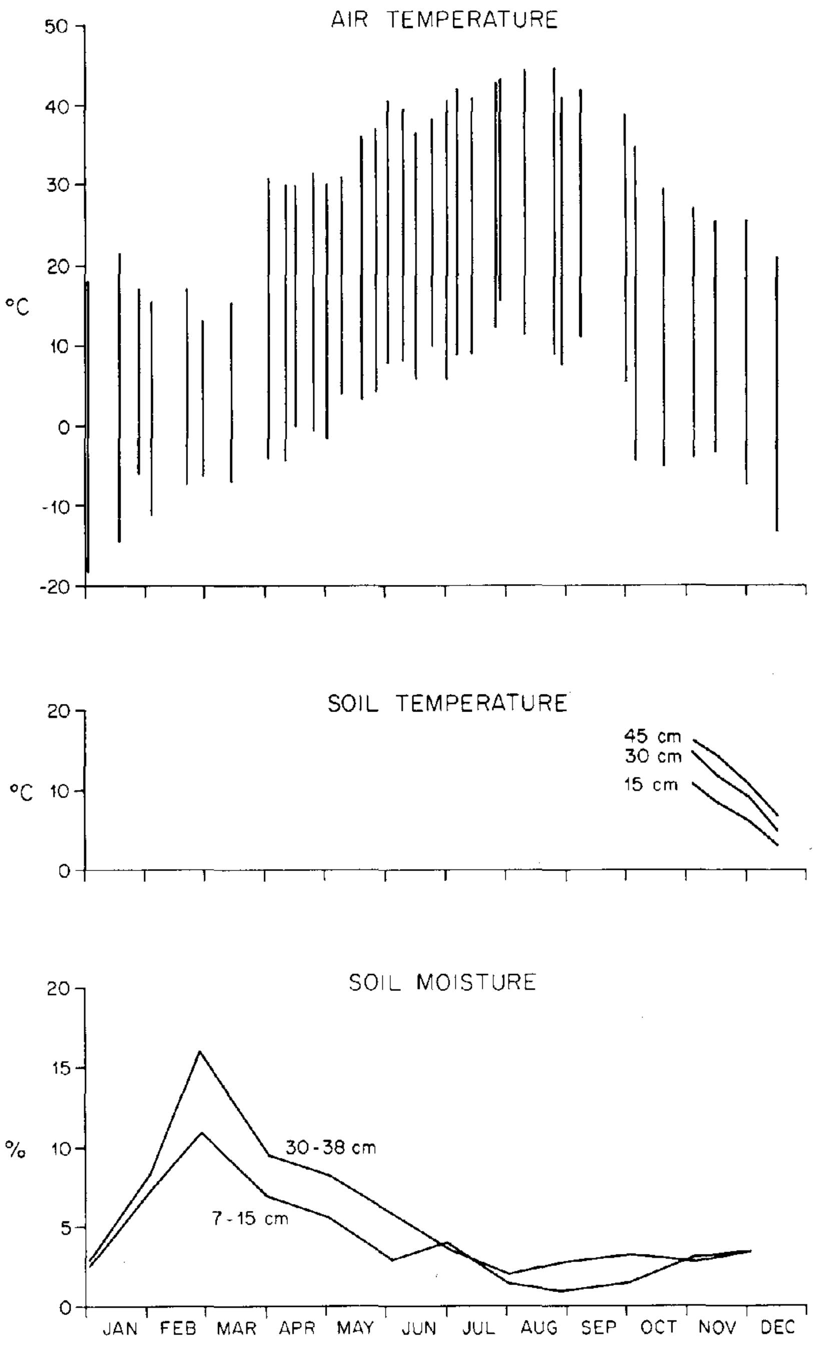

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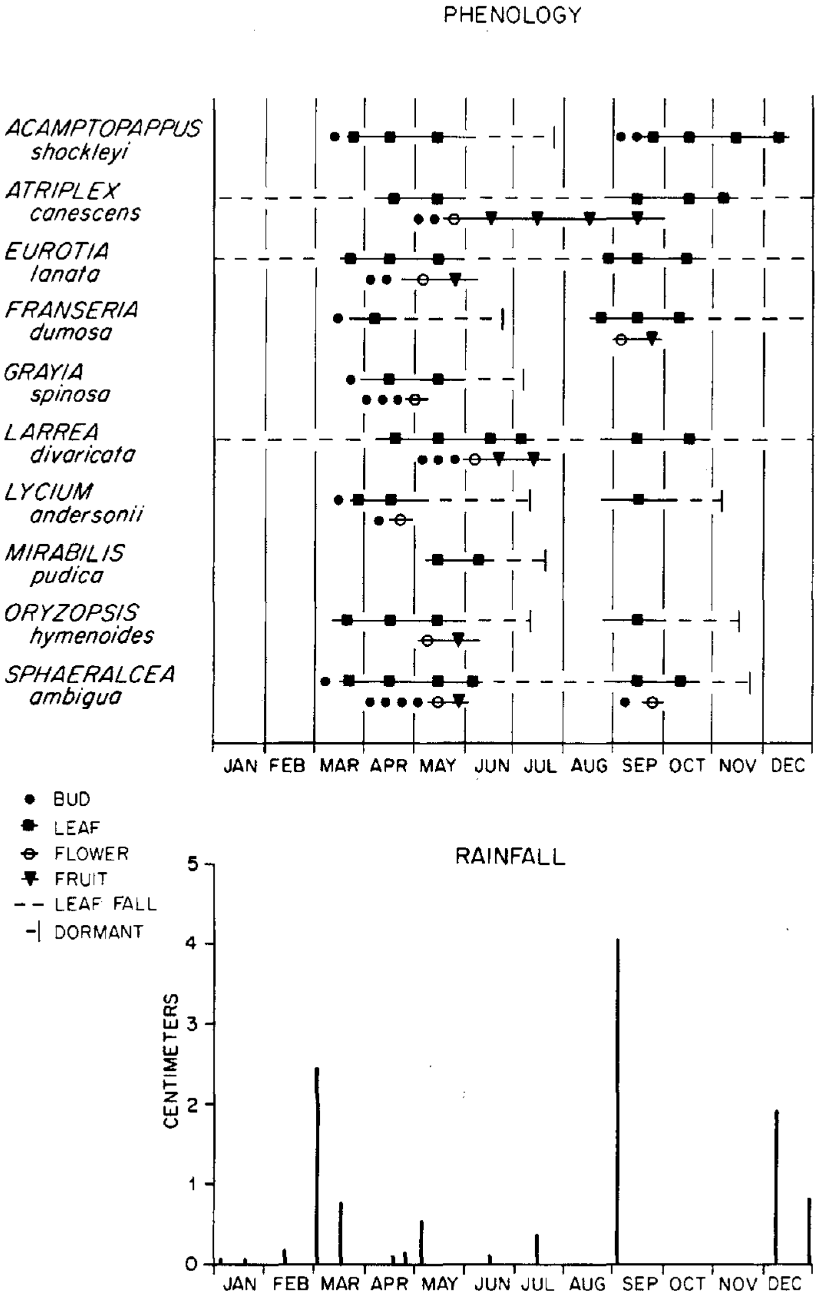

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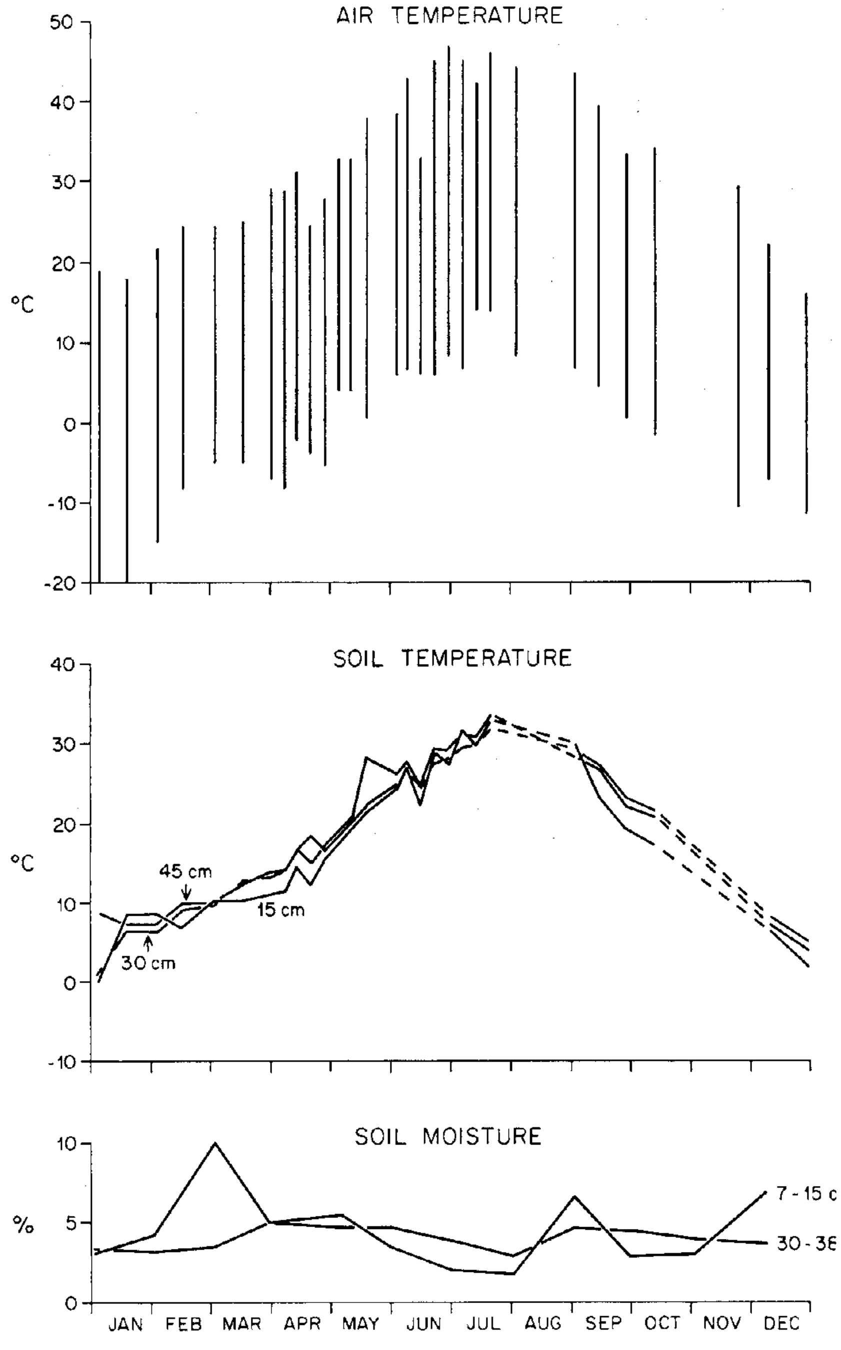

FRENCHMAN FLAT 1970

and Mercury Valley in 1968 and in Frenchman Flat in 1970. The data also reveal some interesting differences in growth patterns among species such as, for example, the unique phenological characteristics of *Krameria parvifolia*.

Rainfall data illustrate the inherent variability of precipitation in the desert. In the northern Mojave Desert portion of the Nevada Test Site, most rainfall of a wide-spread nature usually occurs during the late fall and winter months. Adventitious rainfall occasionally occurs during summer months, but these rains generally are not widespread.

Air and soil temperature data generally show positive correlation, with a characteristic lag in response to changes in ambient conditions at lower depths in the soil. It is of ecological significance that these desert soils warm rapidly to depths of at least 45 cm because the bulk of the plant root biomass lies within this depth of soil. We believe that some shrub species probably respond more positively to the seasonal warming of soil temperature than of air temperature. This would be necessary in order to maintain the integrity of those plant species with cold-sensitive foliage which otherwise would suffer from the widely oscillating ambient temperatures common to the early spring months in the northern Mojave Desert.

Soil moisture data show notable differences from year to year and within the seasons of a given year, depending upon the amount and frequency of precipitation. It is common to these areas that storms with heavy rainfall result in very little percolation of moisture to lower depths in soil. We believe that the depletion of soil moisture plays an important role in triggering leaf fall and summer dormancy of some plant species.

Summary

Phenological and environmental measurements were recorded for several different shrub species and for rainfall, air and soil temperatures, and soil moisture. Results are graphically illustrated to show the correlation of plant responses with changes in environmental conditions from 1968 through 1970 in Rock Valley, Mercury Valley, and Frenchman Flat.

LEAF FORMS IN DESERT VEGETATION

Branching and segmenting of leaves have been reported to be xeric-adaptive mechanisms which help dissipate heat to convective currents in order that plants may survive under climatic conditions which otherwise might be injurious (Lewis, 1969; Taylor and Gates, 1969; Turrell, 1969). The broad leaves of the banana plant, for example, are split into many segments by wind action which contributes to heat dissipation under semi-tropical and tropical conditions (Taylor and Gates, 1969).

Broad-leaved plants in general are poorly equipped to survive under desert conditions. Most leaf forms in desert vegetation are structured to help dissipate heat and also to conserve moisture. This applies especially to shrubs and trees. There are, however, some exceptions which are commonly found in the ephemeral annual species, many of which complete their life cycle only during periods having favorable soil moisture and favorable air temperature.

Phenotypes among certain desert plant species can be distinguished by the size and shape of leaves. Such is the case for two phenotypes of *Larrea divaricata* as shown by measurements of 25 leaves taken at random from plants of the large and small leaf types. The differences in these measurements were significant at the 0.001 level.

Dimensions (mm)	Large type	Small type
Leaf width	10.80	7.16
Lobe length	10.00	6.76
Lobe width	4.44	2.60
Ratio, lobe length:width	2.28	2.70

Photographs of some leaves and shoot structures are shown in Figure 1 (p. 304-305) for several plant species common to the Nevada Test Site to illustrate characteristics which result in survival under the rigorous conditions of the northern Mojave Desert. Among the dominant shrub species indigenous to this desert are those which have long, slender leaf forms and pronounced woody stem structures. The stems contribute most of the standing crop biomass. The amount of foliage produced and subsequent size of the leaves is dependent upon the available soil moisture received during the fall and winter months preceding spring growth. The succulent leaf forms which are produced during moist years retain essentially the same leaf shape but may be several times larger in dimension than leaves produced during dry years. Figure 2 illustrates this point. The species represented here is *Lycium andersonii* which was grown in the glasshouse under different moisture conditions. Herbaceous species tend to have broader leaf forms than do the shrub species.

Figure 1, legends (A) *Salsola paulsenii*, (B) *Salsola pestifera*, (C) Staminate *Ephedra nevadensis*, (D) Ovulate *Ephedra nevadensis*, (E) *Franseria dumosa*, (F) *Eurotia lanata*, (G) *Encelia virginensis*, (H) *Grayia spinosa*, (I) *Acamptopappus shockleyi*, (J) *Krameria parvifolia*, (K) *Stephanomeria pauciflora*, (L) *Hymenoclea salsola*, (M) *Lepidium fremontii*, (N) *Menodora spinescens*, (O) *Salazaria mexicana*, (Q) *Atriplex confertifolia*, (S) *Atriplex canescens*, (T) *Atriplex hymenelytra*, (U) *Psilostrophe cooperi* , (V) *Sphaeralcea ambigua*, (X) *Machaeranthera tortifolia*. (p. 304 - 305)

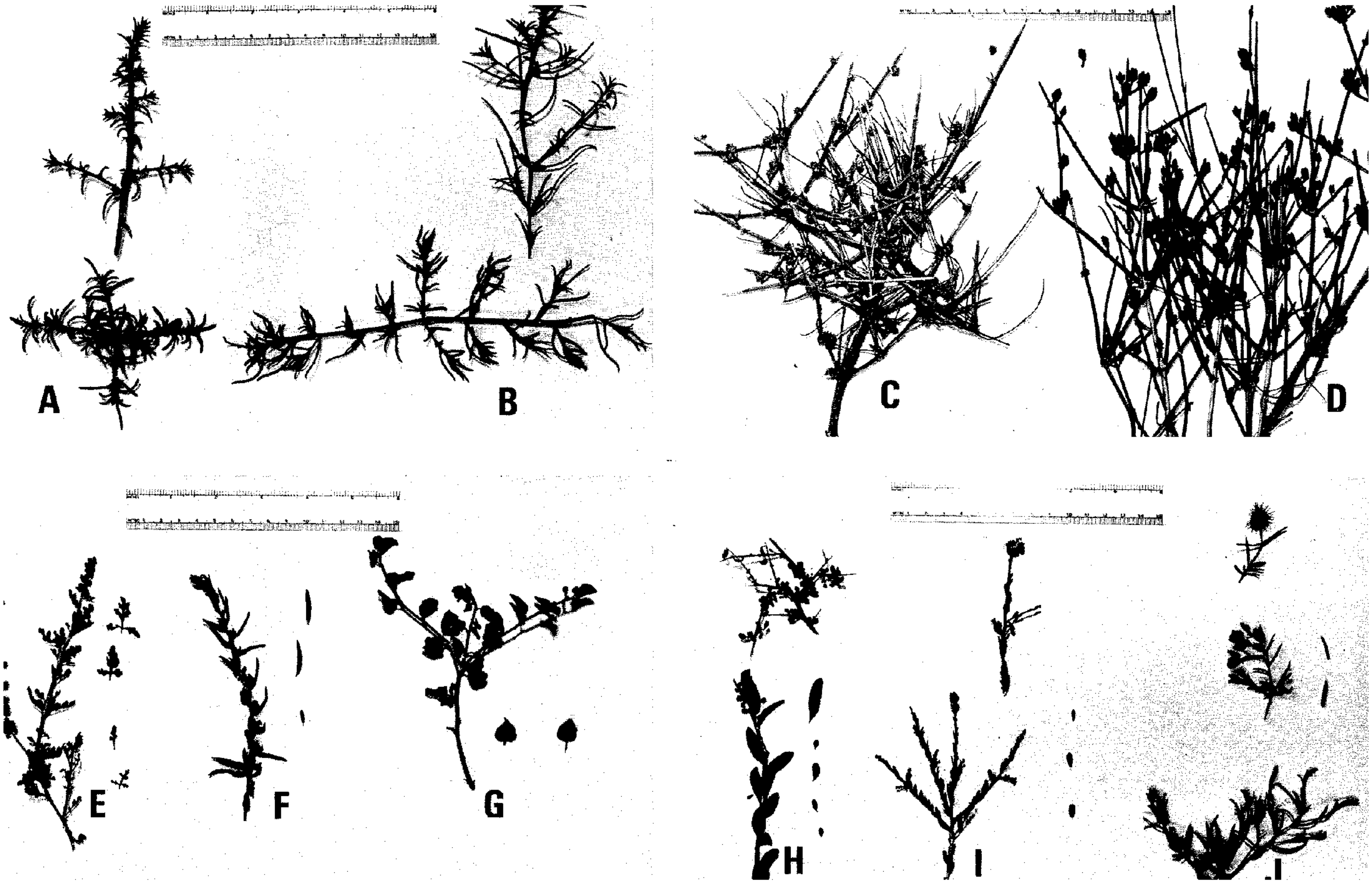
A
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Figure 2. Variations in leaf forms of Lycium andersonii grown under different soil moisture conditions in the glasshouse.

Conclusions

Survival of perennial plants in the Mojave Desert is partly determined by two very basic phenomena. First, the foliage is structured to conserve moisture and dissipate heat. Within these limits plants will respond to moisture or drought by greater or lesser seasonal productivity depending upon the available soil moisture. Second, the perennial species either drop their leaves or the leaves withstand extreme dehydration without harm when seasonal soil moisture becomes exhausted. These plants have the unique capacity to remain inactive under severe moisture stress for several months' duration and continue to survive drought years wherein very little primary productivity occurs.

APPROXIMATE AGE OF SHRUB CLUMPS AT THE NEVADA TEST SITE

Introduction, Methods, Discussion

The usual community situation with shrubs in the northern Mojave Desert is for 2 or more and as many as 7 to 20 individual shrubs to be associated together in a clump or microcommunity (Bradley and Deacon, 1965; Allred and Beck, 1963; Hanson and Churchill, 1961; Wood, unpublished). This type of community structuring is important to many annual plants which also grow in association with the clumps because of favorable soil texture, shading, water relations, soil organic matter, mineral nutrients and/or other factors (Muller, 1953). The structure is also important to animals both above ground and below ground.

The genesis of a shrub clump has not been greatly studied although a recent unpublished study sponsored by Dr. Janice Beatley has attempted evaluation of a hypothesis on the matter. How does a clump get started, what are the pioneering species in it if any, how old do individual species and clumps get, are clumps perpetuated upon death of individuals and renewed within the existing clump? If the latter is the case, have the shrub clumps existed indefinitely?

By methods of counting annual rings, ages of individuals in some clumps which appear to be 100 years old or more were determined.

Since soil organic matter is much higher under a shrub clump than between shrub clumps (in desert pavement for example) it may be possible to estimate how long a given spot has been the location of a shrub clump if the rates of accumulation and degradation of the soil organic matter are known. Such data can be obtained with careful ^{14}C studies and plans are being made to obtain that information. In the meantime some estimates as follows may be used to gain a first approximation.

	kg dry wt/ha
Annual primary production	1,000
Annual amount remaining after animal respiration	750
Annual amount remaining after microbial respiration	75
Soil organic matter under clump	33,000
Soil organic matter in open area	11,000
Difference between two areas	22,000
Years to achieve at 75 kg/ha/yr	293

This estimate indicates that some of the shrub communities might have been in place for as many as 300 years. Since the oldest plants in some of them may not exceed much over 100 years, one must assume that a turnover in individuals within a clump exists. Actually in 1969 many of the clumps in Mercury Valley had new seedlings of *Eurotia lanata*, *Acamptopappus shockleyi*, *Franseria dumosa*, *Larrea divaricata* and other species added to them. That year was a good year for seed germination. New seedlings of these species also appeared in open areas between existing clumps. Whether or not these are pioneers for new communities or whether they will even survive is not yet known.

In the spring of 1969 soil pits were dug in many shrub clumps. Of particular interest was the observation that shrub clumps, possibly in existence for

Figure 1. Soil pit in Mercury Valley showing how caliche layer is partially dissolved underneath a L. divaricata shrub clump.

over 100 years, have a profound effect on underlying caliche layers (see Figure 1 with closeup in Figure 2). The effect, however, was not consistent. The action of organic matter derived from roots (and shoots) had partially dissolved the caliche layer underneath the clump in Figures 1 and 2. This not only could serve to make more soil available to the clump but also as a sump for water to flow into the area below the plants with the surrounding caliche serving as a catchment to divert the water into the sump. This would favor the continuation of the clump and hinder the development of new clumps in surrounding areas. The variability from clump to clump on the nature of the caliche layer may reflect the differences in age of the shrub clump sites.

Animals undoubtedly have a great effect in maintenance of the shrub clump sites. Intense burrowing activity usually occurs within the clumps and this

Figure 2. Close up of dissolved caliche layer in Figure 1.

tends to mix soil, promote aeration, and promote mixing of organic matter in lower layers of the soil. For example, in one soil excavation site in Frenchman Flat there was an undecayed accumulation of leaf and stem material at a depth of about 1 meter due to animal activity.

In an area in Frenchman Flat where old clumps had died (drought or gophers?), new Atriplex canescens plants have grown in the old clumps of dead plants but not in the areas between the old clumps. Growth rings indicate that the new shrubs were 17 years old in 1969. The clump evidently then can continue even if there is a break in direct continuity of the existence of living plants in the clump area.

Summary

An estimate based on soil organic matter differences in shrub clumps in Mercury Valley and adjacent areas of the Nevada Test Site indicate that shrub clumps composed of two or more individuals may be in place for as many as 300 years even though oldest individuals in them at present may be around 100 years old. The genesis of shrub clumps is not known nor is it known how new ones develop. Shrub roots have a tremendously profound effect on caliche layers in the soil in that the long-time presence of soil organic matter tends to dissolve or soften the layers.

EFFECT OF DECOMPOSING *ARTEMISIA* LEAVES ON SUBSEQUENT GROWTH OF *SALSOLA KALI*

Introduction

Salsola kali commonly invades land which has been disturbed and on which other plant species have been killed. Both the soil disturbance and the changed water conditions in the soil appear to be important (Rhoads et al., 1967; Wallace et al., 1968). In one particular nuclear event there appeared to be a 2-year lag between killing of the old plants which in this case were *Artemisia tridentata* and the invasion of *S. kali*. One possible reason for the lag was a delay in the availability of seed due to the space remoteness of the event and another is that *A. tridentata* plant material while decomposing has an inhibitory effect on *S. kali*. This latter hypothesis was tested. Allelopathy is a subject of considerable former and recent investigation (Bonner, 1950; Muller, 1969; Beetle, 1960; Buchanan, 1968; McNaughton, 1968; McPherson and Muller, 1969; Muller, 1967; Naqui, 1969; Schlatterer and Tisdale, 1970; Wilson and Rice, 1968).

Materials, Methods, Results and Discussion

A. tridentata leaves were dried and ground with a Wiley mill, and then mixed with Yolo loam soil at a rate of 25 g per 500 g soil.

S. kali were germinated in Yolo loam soil; 24-day old seedlings were transplanted into treated and control pots in triplicate. Nitrogen as 5N $Ca(NO_3)_2$ was added to each pot at the rate of 2.5 ml at 2-week intervals.

The plants in the soil with the organic matter were all wilted in 4 hours while the control plants were not.

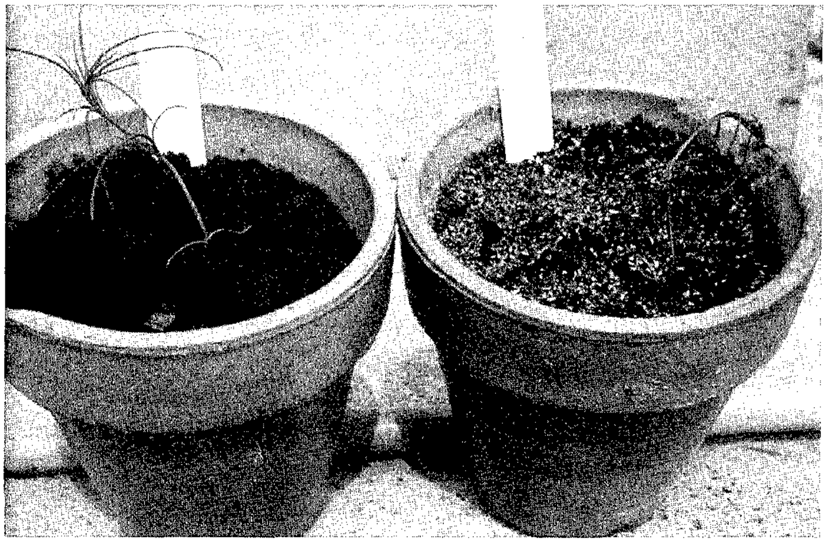
A second set of *S. kali* plants was transplanted 11 days after the experiment started into the soil which had received the organic matter. The new *S. kali* plants were the same age as the original six. After 27 days one of the original *S. kali* plants in 5% *A. tridentata* had died. The control plants were about ten times larger than the plants in soil with the organic matter.

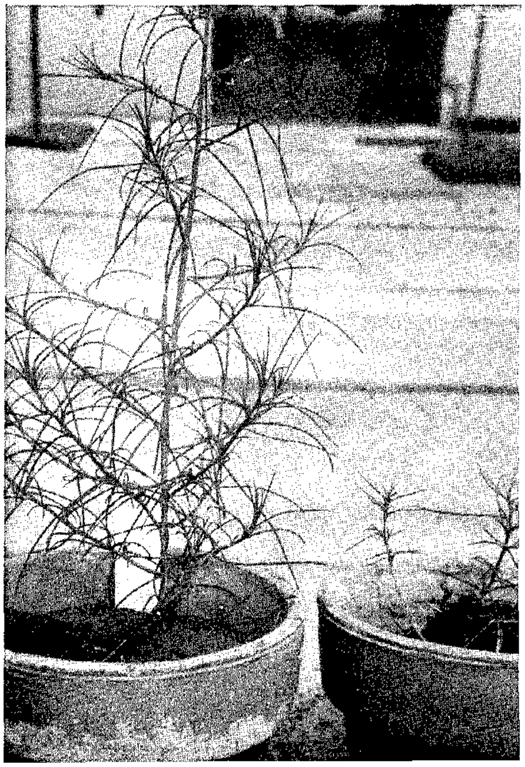
Pictures in Figure 1 were taken 4 hours after the experiment began and then 27 days later. *A. tridentata* leaves definitely had an adverse effect on both growth and survival of the *S. kali*. This indicates, but does not definitely establish, that *A. tridentata* can have an allelopathic effect on *S. kali*. This perhaps is the more logical explanation for the behavior of *S. kali* in the *A. tridentata* community mentioned in the introduction.

A. tridentata quite likely has an allelopathic effect on other plants and perhaps even on itself. *A. tridentata* occurs singly and new seedlings are never near the old plants; they are in open spaces between the old plants.

See page 152 for explanation of more recent nomenclature of the *Salsola* species.

Figure 1. (top) Representative seedlings 4 hours after transplanting to soil with and without _A. tridentata_ organic matter (plant on right received the organic matter). (bottom) Plants 27 days after the treatments.





LEAF TEMPERATURES OF DESERT PERENNIALS IN SUMMER MONTHS

Gates et al. (1968) have reported that of seven desert species studied all except Opuntia species had leaf or blade temperatures near the ambient temperature (within 2 or 3°C). The temperature of the Opuntia was 10 to 16°C higher than the ambient. Drake and Salisbury (1970) have also recently studied leaf temperatures. Wallace et al. (1967) reported that tobacco leaves could be 10°C above ambient when grown to be phosphorus deficient which caused stomata to fail to open. It can be expected that cooling effects are related to transpiration and to the ability of plants to obtain water that can be transpired. The relationship of transpiration to leaf temperature has been reviewed by Gates (1968).

Materials and Methods

A portable infrared sensor (Barnes Engineering Co.) of the type described by Gates et al. (1968) was used to measure leaf and blade temperatures of plants at the Nevada Test Site in July and September 1969 and in July 1970. Relative humidity measurements were made with a portable thermistor psychrometer (Atkins Technical, Incorporated).

Experimental Results

Blade surfaces of Opuntia basilaris and Yucca schidigera were often 13°C above ambient with 35°C ambient, no wind, 22% relative humidity (Table 1). The temperatures inside the blades were lower (up to 5°C) than those at the surface. The suggestion of Gates et al. (1968) that plants such as Opuntia may need specially adapted proteins to function at high temperatures may not be as important as suggested by them since temperatures inside blades were lower than at surfaces.

Table 1. Temperatures of surface and inside O. basilaris and Y. schidigera blades.*

Plant and part	°C
Ambient	35
O. basilaris surface	48
O. basilaris inner	43
Y. schidigera surface	48
Y. schidigera beneath surface	46
Y. schidigera inner	44

*Readings were taken immediately upon cutting to avoid cooling due to evaporation of the cut surface.

Leaves of the other species examined were very near the ambient temperature (Table 2). Irrigation seemed to result in slightly lower leaf temperatures. In the afternoon when stomata usually are closed wind speed seemed to be a dominant factor on blade temperature of Opuntia species and Yucca species. Blade temperatures were very little above ambient under the convection currents and obviously were related to the effect of the wind.

For readings taken at 7:00 p.m. with no wind and ambient temperature of

Table 2. Leaf temperatures of several plant species as difference from the ambient temperatures.

Species or description	A.M. (no wind)	P.M. (windy)	P.M. (windy) (irrigated)
	°C	°C	°C
	Ambient temperature		
	32	44	44
	Difference from ambient		
Larrea divaricata	+ 1	+ 2	+1
Salsola iberica	- 1	—	+4
Atriplex confertifolia	0	—	—
Franseria dumosa	+ 1	—	-1
Krameria parvifolia	+ 1	+ 3	+1
Eurotia lanata	- 2	+ 2	+2
Yucca schidigera	+13	+ 3	+1
Ephedra nevadensis	0	—	—
Bare soil in sun	+14 to 18	+16	+8
Bare soil in shade	0	+ 4	+1
Opuntia species in sun	+ 7	+ 3	+3
Opuntia species in shade	0	—	—
Juniperus osteosperma	+ 2	—	—
Artemisia tridentata	- 3	—	—
Yucca brevifolia	- 2	—	—
Lycium andersonii	- 4	—	—

34°C and near Cane Springs where there is a constant source of water at or near the soil surface, all species had leaf temperatures from 4 to 9°C below ambient (Table 3).

Table 3. Leaf temperatures of plants at 7:00 p.m. in July (17th) near Cane Springs (34°C and 37% relative humidity).

Plant	Leaf temperature Δ°C from ambient
Typha species	- 8
Euphorbia species	- 8
Oenothera megalantha	- 4
Atriplex canescens	- 6
Coleogyne ramosissima	- 4
Salix gooddingii	- 6

In Table 4 are data taken at 4:00 p.m. on July 21, 1970 for plants growing in an area which was irrigated continuously with enough water (see page 349) to maintain the soil in a saturated condition down to the caliche layer compared with an area not irrigated. This latter area was extremely dry at time of sampling with a soil moisture level of about 2%. Results indicated that irrigation resulted in a decrease of leaf temperatures of as much as 7°C for some species at 4:00 p.m. Greater differences seemed to obtain for species most physiologically active. Krameria parvifolia which is active during hot dry periods (see page 164) seemed to function at leaf temperatures somewhat higher than those of most other species during mid-day ambient conditions.

Table 4. Effect of irrigation on leaf temperature measurement of some plants near Mercury, Nevada. (4:00 p.m., July 21, 1970, sunshine, air temperature at 38°C, 37% relative humidity, air movement about 10 km per hour.) Means of 3 readings.

Species	Nonirrigated °C	Irrigated °C
Franseria dumosa	43	36
Atriplex confertifolia	45	39
Larrea divaricata	42	37
Krameria parvifolia	47	40
Yucca schidigera	41	40
Salsola iberica	42	40
Ephedra funerea	41	39
Sphaeralcea ambigua	—	32
Opuntia species	45	43
Stipa speciosa	—	40
Erodium cicutarium	—	32
Eurotia lanata	44	40
Bare soil	51	41

Summary

Temperatures of leaves or blades of Opuntia basilaris and Yucca schidigera in the a.m. and without wind blowing tended to be 7 to 13°C above ambient. The temperature inside the blades was about 5°C cooler than that at the surface when the surface was higher than ambient. In the p.m. and especially when the wind was blowing, leaf temperatures of all species were 1 to 2°C above ambient. In the a.m. they tended to be 1 to 2°C or more below ambient for species other than Yucca and Opuntia. Irrigation tended to decrease leaf temperature by several degrees for some species.

SOME EFFECTS OF AN ARTIFICIAL STREAM ON DESERT VEGETATION

Water is the most limiting factor affecting primary productivity in a desert ecosystem (Rosenzweig, 1968; Went, 1968). The possibility exists that an excess of water may be injurious to at least some desert plants; however, the obligatory nature of dry soil for plant species common to places like the Nevada Test Site is not known. The purpose of this study was to assess some of the effects of a stream of water flowing intermittently through a desert system.

The site selected for this study was down slope from the sewage processing system for Mercury, Nevada. Waste water periodically had run through some of the dry washes for six to eight years before the present sewage processing system was established (Figure 1), and the *Larrea divaricata* and *Franseria dumosa* shrubs had responded with vigorous growth (Figure 2). Several shrub species grew no larger than they did in outlying areas but they were more plentiful in or near the dry stream beds where processed sewage water flowed intermittently. Common dry wash species, such as *Hymenoclea salsola*, grew vigorously as did several of the grass species, including the introduced *Bromus rubens*, in the same washes.

Two artificial streams were established specifically for additional observations for this study. One was established in one of the dry washes downstream from a newly constructed terminal holding pond of the sewage disposal system. A siphon source was installed so that about 250 liters per minute of water was discharged, forming a stream that was permitted to flow for seven days of each month. The water flowed downstream for a distance of about 2 kilometers each time. The quality of the water is given in Table 1.

Table 1. Chemical analysis of reclaimed sewage water.

Element	1967 μg/ml	1969 μg/ml
Calcium	18.4	12.5
Magnesium	3.1	2.8
Potassium	16.0	16.5
Sodium	263.0	266.3
Nitrogen	5.0	5.0
Cl^-	132.3	108.4
$SO_4^=$	8.3	7.4
Organic matter	72.0	80.0
Sodium adsorption ratio	21.2	23.6

Plots, 30 m x 30 m, were established along the wash so that the stream passed through the center of each plot. Reference photographs were taken at selected points when the stream started flowing, and later at yearly intervals, in order to record the gross changes which occurred in vegetation growing near the stream. Examples of these gross effects are shown in Figures 3 through 9.

The most pronounced effect in the stream plots during the first year after the treatment started was the rapid production of grasses and annual species.

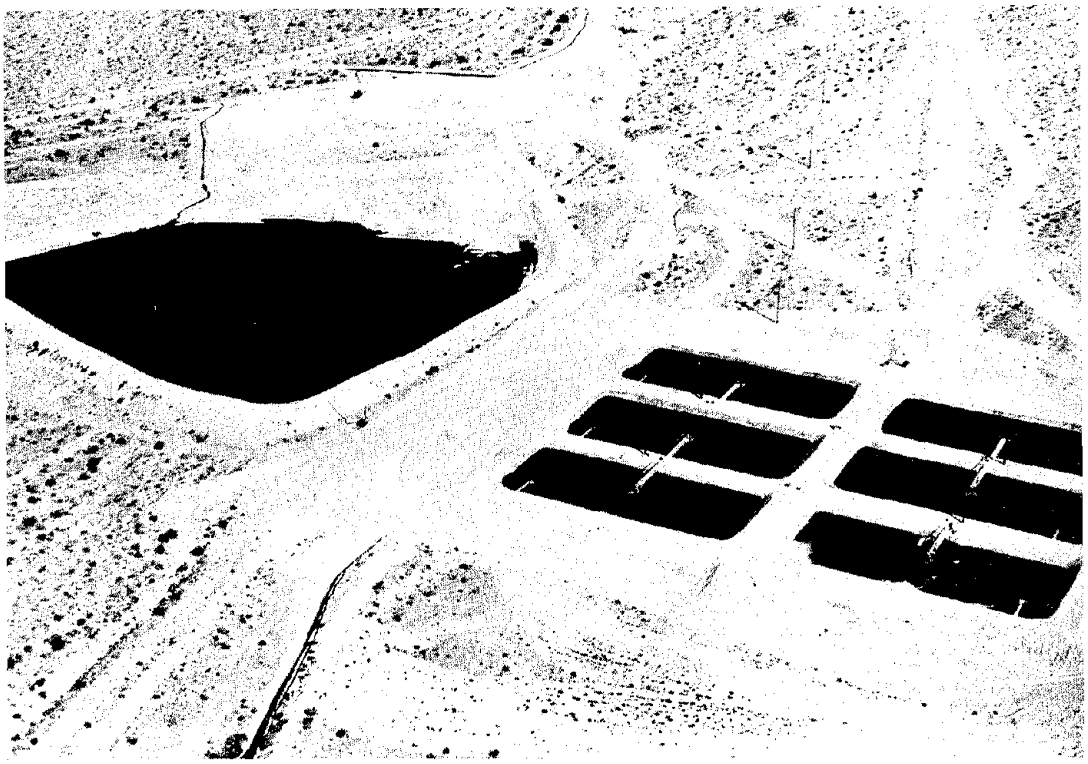


Figure 1. Aerial photo of part of the sewage processing system for Mercury, Nevada. Excess reclaimed water is periodically discharged into dry washes below the terminal holding ponds (not shown in photo).

Figure 2. A dry wash through which reclaimed sewage water had flowed periodically during an 8-year period.

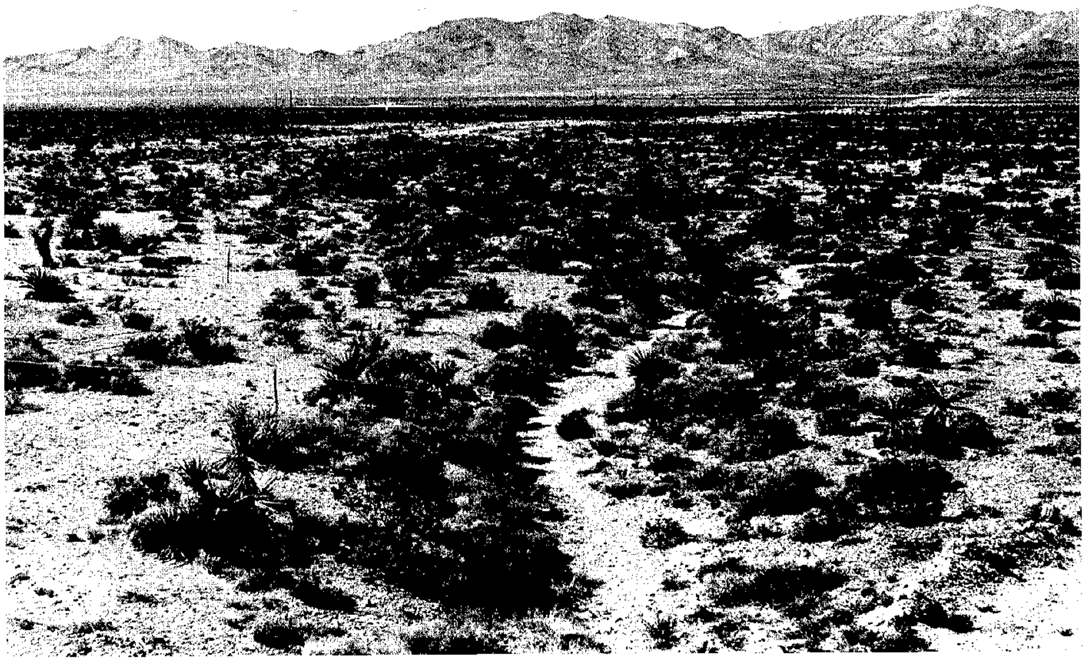
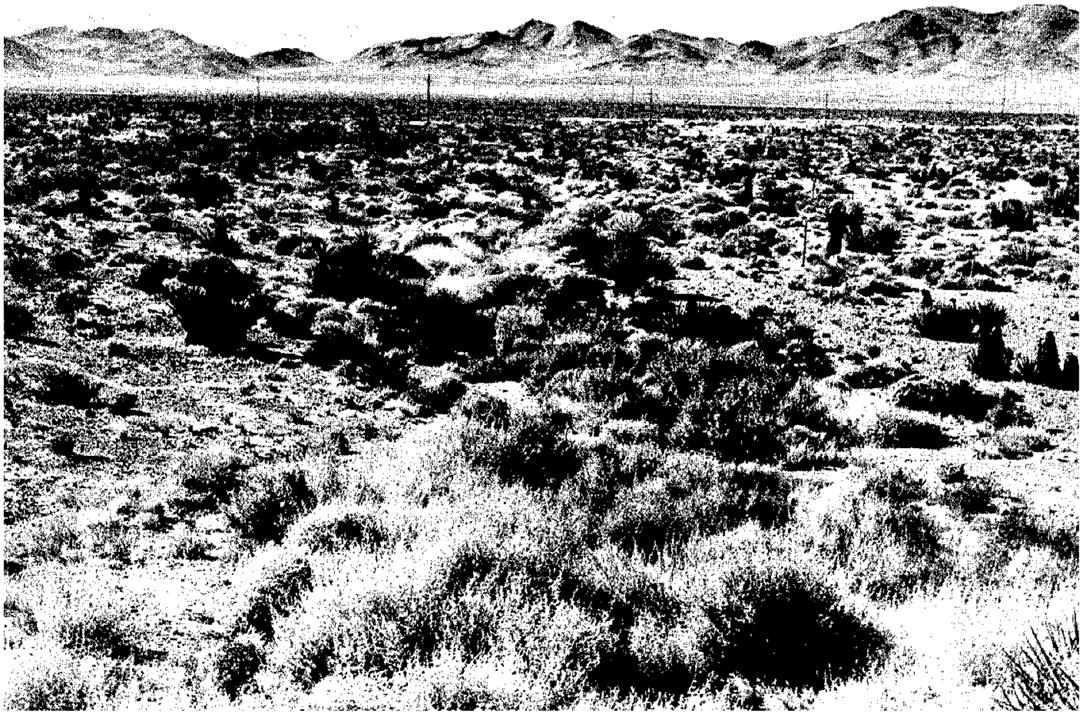


Figure 3. Downstream view of an artificial stream which began flowing for one week of each month in early spring of 1967.

Figure 4. Photo of same site as in Figure 3 taken in late 1969, 30-months after the artificial stream was established. New plants in foreground are largely Salsola species.



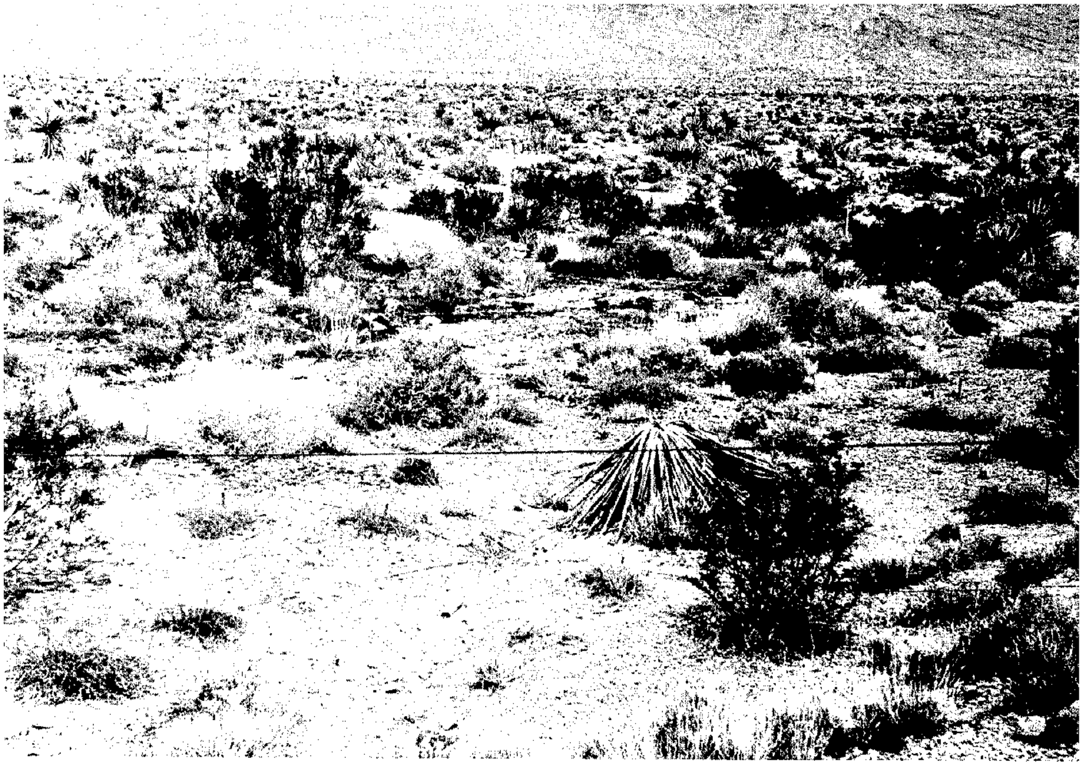


Figure 5. Across-stream view taken in early spring of 1967 after water started flowing.

Figure 6. Same view as in Figure 5 taken 30 months after the artificial stream was established.

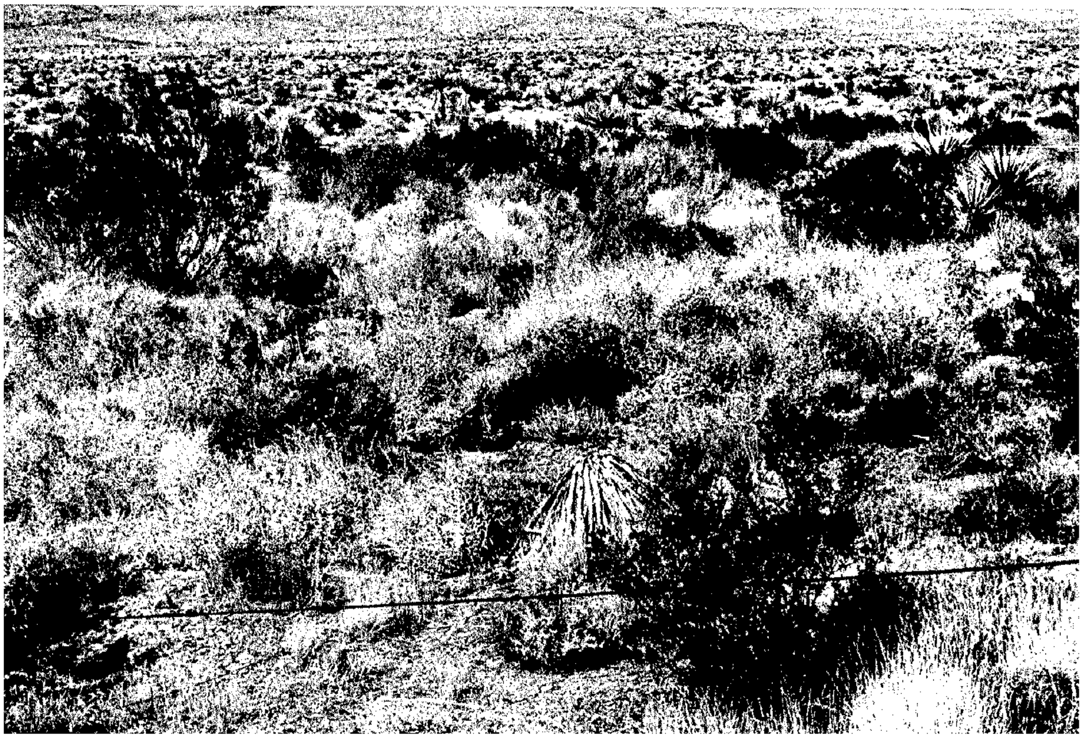


Figure 7. Upstream view taken in the early spring of 1967. Note the sparseness of grasses.

Figure 8. Same view as Figure 7 taken 6 months after the artificial stream flow began. Note the dense ground cover of grasses, predominantly Bromus rubens, an introduced species to this ecosystem.

Table 2 contains data on the unit area biomass of annual vegetation harvested along a transect of the stream bed about six months after the artificial stream flow began. The most common grass was an introduced species, *B. rubens* (Beatley, 1966). The predominant annual species were *Descurainia pinnata* and *Eurodium cicutarium*. These grasses and annuals again were ubiquitous during the spring months of the second year of treatment; however, the pattern of ground cover markedly changed during the summer months of 1969 with an invasion of the stream area by the *Salsola* species. At the time of this writing (winter of 1970) the artificial stream area had become heavily clogged with dried brush consisting mainly of the remains of the grasses and annual plant species. Most of the perennial plant species growing in or near the stream bed were in a sense completely obscured by the annual ground cover, and only the presence of the larger sized shrubs could be easily detected when walking through the stream area. There was no indication in three years that perennial plants were adversely affected by the new, heavy ground cover of annual vegetation. The study must be continued for several years to demonstrate detrimental effects from annual ground cover competition.

Table 2. Biomass of annual plant species taken at 3 m intervals along a transect line across a wash through which an artificial stream flowed one week of each month.

Sample interval	Relative species percentages				Dry biomass
	B. rubens	*E. cicutarium*	*D. pinnata*	Other	
No.	%	%	%	%	g/m^3
1	75	10	10	5	22.6
2	60	20	20	0	85.2
3	50	0	50	0	24.8
4 ↑	50	5	40	5	170.2
5 wet stream	100	0	0	0	1509.3
6 bed	100	0	0	0	1934.8
7 ↓	10	5	80	5	673.7
8	50	25	20	5	38.8
9	5	90	5	0	28.0
10	75	20	5	0	21.6

Most of the perennial plants have responded favorably with vigorous growth to the artificial stream. This was especially noticeable during the low rainfall year of 1970 when vigorous, plant growth occurred in the stream area compared to sparse productivity in surrounding areas. *F. dumosa* remained green near the stream bed throughout the year in contrast to its usual behavior of being dormant for more than half of the year. This resulted in some foliage of *F. dumosa* being frozen in the stream area during cold periods of each successive winter because it was in new flush growth when freezing occurred. Suppressive effects of the stream on plant growth were noticed during the spring months after a prolonged period of below freezing temperatures in January of 1968. We noticed the death of several small *L. divaricata* seedlings growing in and near the flowing stream bed within a few months after stream-flow was started. This observation, along with similar effects which have occurred in glasshouse culture of this shrub, indicates that excessive moisture and/or poor

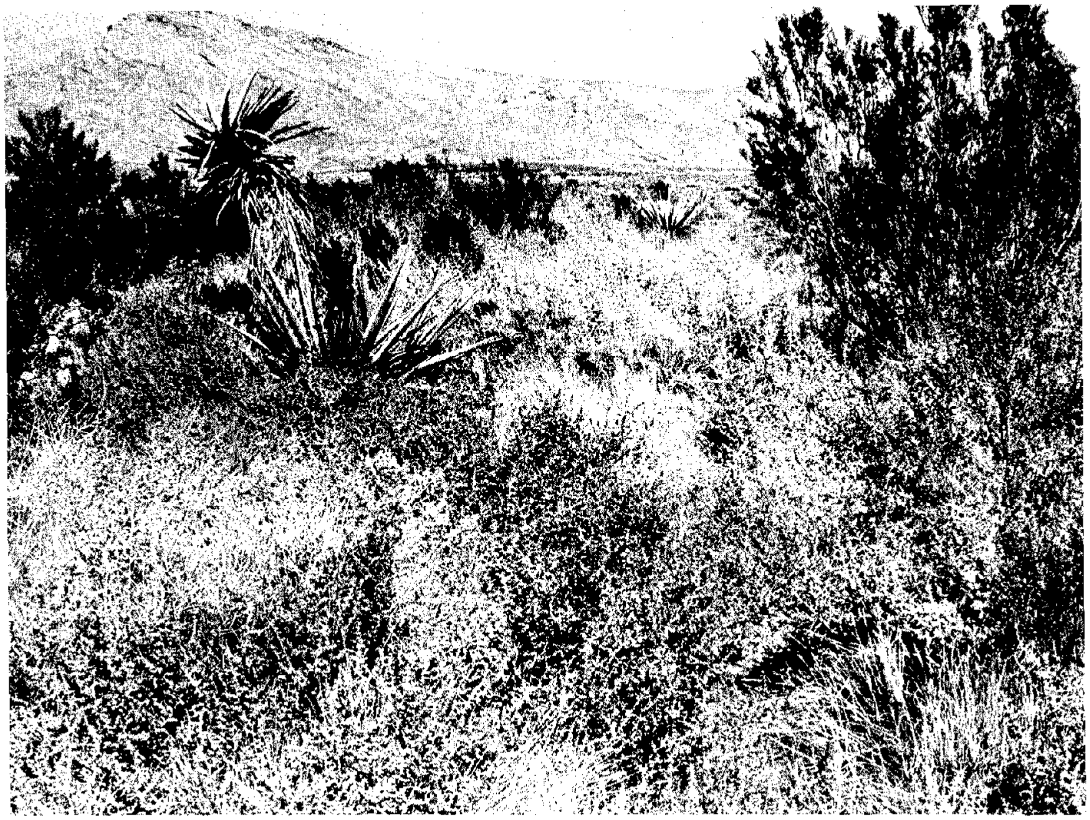


Figure 9. Same view as Figures 7 and 8 taken 40 months after stream flow began. Note how the ground cover was taken over by Salsola species and grasses.

aeration in the root zone may cause adverse effects on young L. divaricata shrubs. In some cases L. divaricata, F. dumosa, Eriogonum inflatum, and Sphaeralcea ambigua have produced yellow foliage indicative of a high bicarbonate induced iron chlorosis.

The Ephedra species have shown no particular response to the artificial stream during the period of treatment observation. The same can be said of Yucca schidigera. These and other slow-growing perennial species may require more time in which to demonstrate their response to the artificial stream.

Krameria parvifolia continued to flower until October in the stream area. This species usually completes its flowering period by the end of July in the study area which is not influenced by the artificial stream.

A modification of the artificial stream treatment was made in March 1970 which resulted in some striking, gross results. Water was siphoned at about 6 liters per minute into a small ditch system that wound back and forth along the contour lines of a flatland area below the pond. The distance between the ditches varied from 1 to 3 meters. Figures 10 and 11 illustrate the gross differences which occurred in the ground cover of the area after about six months of irrigation during alternate weeks. The grasses and annual plant species common to this area showed tremendous growth response, flowering, and seed production. Among those perennial species which immediately responded were F. dumosa, L, divaricata, S. ambigua, Lycium andersonii, Ephedra nevadensis, Atriplex confertifolia, Eurotia lanata, Grayia spinosa and K. parvifolia. The Salsola species did not invade this area the first year but they are expected

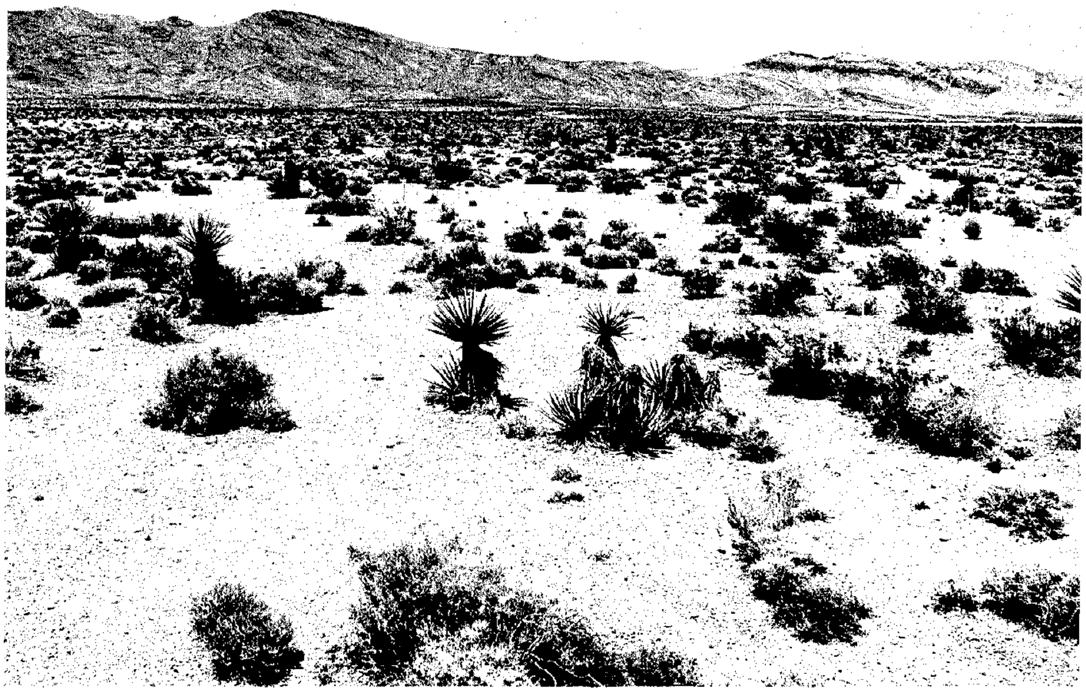


Figure 10. Area of desert flatland before irrigation was started.

Figure 11. Desert flatland about 6 months after irrigation with a contour ditch system. Note the very heavy ground cover of annual plant species and grasses. The small stream flows from near top right of photograph and winds back and forth across the area.

Table 3. Mineral contents in plants growing in stream area and in area beyond influence of stream.

Plant species	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Al	Si	Ti	Mo	Sn	Sr	Ba
	% of dry tissue					ppm of dry tissue											
Leaf samples from wet stream area																	
G. spinosa	0.47	1.40	9.96	0.49	1.39	29.4	10.2	81.9	111.9	28.5	19.1	0.06	0.5	3.2	12.9	17.7	11.4
F. dumosa	0.46	0.16	4.18	1.85	0.62	33.3	10.5	115.6	35.9	222.6	214.2	0.17	10.5	1.5	10.1	85.7	26.2
S. ambigua	0.51	0.17	2.32	1.38	0.25	23.7	11.6	88.2	33.9	89.8	230.0	0.11	13.2	0.7	8.5	37.2	27.7
L. andersonii	0.28	1.09	1.56	3.79	1.11	—	4.8	48.9	52.3	110.7	103.8	0.08	3.5	5.4	8.8	131.1	61.6
L. divaricata	0.13	0.17	2.53	0.70	0.11	20.6	8.4	126.7	24.2	52.8	203.5	0.12	7.5	2.8	11.8	45.3	24.4
Stem samples from wet stream area																	
G. spinosa	0.17	0.16	3.48	0.56	0.50	34.2	27.4	28.2	21.1	20.6	61.4	0.04	0.7	1.7	7.6	41.1	26.1
F. dumosa	0.19	0.17	2.20	0.95	0.35	20.9	16.6	32.5	26.9	39.7	85.5	0.04	2.0	2.8	5.7	60.2	55.1
S. ambigua	0.23	0.17	2.50	0.71	0.10	23.1	13.2	18.4	6.7	13.5	64.6	0.03	1.4	2.0	4.5	63.2	72.3
L. andersonii	0.09	0.10	0.40	1.51	0.23	40.0	32.6	245.7	28.0	15.7	542.2	0.23	12.1	1.0	13.8	73.2	30.9
L. divaricata	0.10	0.16	0.82	0.75	0.15	26.0	10.1	138.5	21.9	24.7	218.4	0.15	6.7	2.8	4.7	69.7	36.4
Leaf samples from area beyond influence of stream																	
G. spinosa	0.09	0.59	8.33	2.15	1.16	19.0	7.8	130.5	127.5	36.5	195.6	0.13	5.0	0.7	16.0	57.8	21.5
F. dumosa	0.34	0.15	3.27	1.68	0.64	16.4	15.6	158.1	34.9	197.4	332.6	0.21	22.4	1.9	8.2	87.3	17.6
S. ambigua	0.24	0.11	2.37	1.53	0.38	11.9	19.1	202.1	78.5	132.1	457.5	0.23	32.0	1.2	10.2	60.0	22.3
L. andersonii	0.08	0.49	1.96	4.23	1.65	17.1	5.2	89.1	48.6	122.2	213.1	0.12	6.4	6.4	5.7	141.0	28.1
L. divaricata	0.22	0.16	1.08	0.97	0.36	5.5	12.2	465.1	52.4	70.9	711.5	0.64	36.7	0.7	5.9	56.9	31.5
Stem samples from area beyond influence of stream																	
G. spinosa	0.39	0.04	0.98	1.36	0.33	21.3	21.8	236.5	54.0	14.2	260.0	0.12	16.9	0.6	39.5	52.7	13.7
F. dumosa	0.14	0.16	2.54	0.79	0.52	16.6	17.5	95.2	32.4	32.8	195.0	0.10	4.5	1.1	25.4	65.3	26.2
S. ambigua	0.10	0.12	1.87	1.16	0.25	11.6	22.8	163.5	29.7	24.7	324.3	0.16	17.4	1.7	4.1	69.4	34.3
L. andersonii	0.09	0.04	0.77	1.37	0.23	14.1	34.3	236.0	25.9	18.5	715.8	0.25	15.5	1.2	7.7	84.2	21.0
L. divaricata	0.30	0.14	0.80	0.70	0.31	11.2	26.4	290.9	46.1	44.3	557.7	0.65	51.3	0.3	1.4	46.4	26.3

to do so in successive years. Most of the deciduous plant species remained in leaf flush from three to five months beyond their normal time of defoliation under natural conditions.

Samples of plant foliage were taken from the wet areas near the stream and from outlying dry areas for three successive years. These samples were analyzed for mineral content and the results are summarized in Table 3. The most pronounced effect of the artificial stream was an increase in sodium and zinc contents of plants growing in the wet areas. This may reflect to some extent the relatively high sodium content of the stream water (Table 1). The wet soil also tended to decrease iron content of leaves.

Summary

Water is the most limiting factor of primary productivity in the desert ecosystem. Species of annual plants, native and introduced grasses, and rapidly growing perennial herbs and shrubs responded favorably to supplementary moisture from an artificial stream source. This response was in the form of markedly increased growth, higher density of individual plants, introduction of new species, especially grasses, and prolonged new leaf flush. Freezing of foliage occurred for some species which remained in new leaf flush during the winter months. Plant species which normally are slow growing showed little or no response during the three-year period of this study. More time may be necessary for them to respond. The sodium content was higher in plants growing near the flowing stream which may be a reflection of the relatively high sodium content of the water used in this study. Zinc content of leaves was increased and iron was decreased for leaves of plants growing near the stream.

EFFECT OF SOIL TEMPERATURE ON WATER RELATIONS OF SOME DESERT PLANTS GROWN IN A GLASSHOUSE

Desert plants have various mechanisms for coping with low water supplies. Some "avoid" water stress by becoming leafless and dormant as drought and heat of summer approaches. Others "avoid" water stress by very deep rooting to water tables. These plants are phreatophytic. Other plants are able to grow in high salt concentrations by using the salt as a means of creating high water potentials in leaves which facilitate water absorption along a gradient. Other plants are truely xerophytic and have developed mechanisms and structures for survival under high water stress. Most of these mechanisms are not well understood. The purpose of this report was not to explore mechanisms of water absorption or conservation by plants but to obtain preliminary information on water use by some species when grown in soil maintained at different root temperatures in an attempt to determine something of this component of the environment on behavior of these species. Only the physiological process of transpiration was considered.

Materials and Methods

Three tanks were set to different temperatures, first by means of refrigeration to cool below desired temperatures and then with heating coils with Fenwall regulators to heat to desired levels. Temperatures used in this study were 10, 18 or 21, and 35° C. Plastic pots with no drain holes were weighed and filled with sufficient Yolo loam soil to give 2000 g moisture-free soil per container. Test plants were seeded and allowed to become established before experiments were begun. Vermiculite (100 g/pot) was added to the top of the soil of each pot to decrease transpiration. Before an experiment started both fresh and dry weights of similarly grown plants were obtained. Pots with soils and plants which had been transplanted to them were weighed daily and soil moisture returned to desired levels by inserting water into the soil by syringe and needle. In some tests no water was added and the test was concluded when the plants at the highest soil temperature appeared to be near permanent wilting.

Plant species used in the study included Atriplex lentiformis (Torr.) Wats., Salsola pestifera A. Nels., Sporobolus airoides (Torr.) Torr., and Artemisia tridentata Nutt. These species represent a partial halophyte, 2 xerophytes, and a phreatophyte.

Water use per unit of new growth and per g dry weight were calculated from the data.

Experimental Results

A comparison of water use per gram of new growth for S. pestifera is shown in Table 1. The 12% soil moisture level was chosen as a moderately low level for this soil (0.7 bars). Water transpired per g new growth was increased with increasing soil temperature when the soil moisture was maintained but when it was not maintained it increased much less. This means an increased efficiency was experienced as water stress increased. Greater resistance to water loss seemed to occur with increasing soil temperature under these conditions.

Water use by S. airoides was changed little by increasing soil temperature when soil moisture was maintained but there was a trend toward greater effi-

Table 1. Change in dry weight and water use by S. pestifera at different soil temperatures in a 10-day period (summer).

Water regime— % soil moisture		Soil temp	Increase in dry weight*	Water transpired		Evapotranspiration	
				per g dry wt	per g new growth	per g dry wt	per g new growth
Start	End	°C	g	ml	ml	ml	ml
12	12	10	.334	63	117	21	40
12	12	21	.249	127	271	159	348
12	12	35	.284	178	363	329	662
10	10	10	.160	68	188	9	25
10	10	21	.317	96	183	126	243
10	10	35	.210	218	519	388	924
12	11	10	.227	70	159	19	44
12	8	21	.224	100	228	137	313
12	5	35	.100	65	250	282	1100
F value		—	3.0*	75.6**	10.6**	104.4**	13.7**
L.S.D. .05		—	0.110	18	126	42	210
L.S.D. .01		—	—	25	173	57	288

*Initial dry weight of plants was 0.293 g.

ciency for increasing soil temperature (Table 2). The reason for this was probably related to increasing dry matter production for the two highest soil temperatures relative to the lowest. When soil moisture was not maintained, dry matter production was decreased for the two highest soil temperatures and water use efficiency was higher at 18°C but not at 35°C. It would appear that the high soil temperature with limiting soil moisture increased the resistance to water flow in the plants, resulting in increased efficiency.

Table 2. Water use by S. airoides at 3 soil temperatures with and without maintenance at a starting level of 12% soil moisture (15-day study).

Soil temp. °C	g dry weight	g new growth	Transpiration ml/g dry weight	Transpiration ml/g new growth
		12% soil moisture maintained		
10	0.88	.38	118	138
18	2.17	1.67	61	128
35	1.41	.91	65	100
		12% soil moisture allowed to become depleted		
10	.91	.41	114	255
18	.76	.26	186	538
35	.70	.20	86	302

In contrast to S. pestifera, however, water transpirational efficiency was lower with limiting water than with water maintained.

Maintenance of 15% soil moisture with A. lentiformis itself reduced growth relative to drier soil (Table 3). Transpirational water use efficiency was decreased by increasing soil temperature when the soil moisture was maintained. When soil moisture was not maintained, transpirational efficiency was increased between 10 and 18°C. At the highest soil temperature without water maintenance, growth was greatly decreased and the transpirational efficiency decreased. In these data also there is indication that low soil moisture at high soil temperatures results in greater efficiency in transpiration even though dry matter production may be decreased.

Table 3. Water use by A. lentiformis at 3 soil temperatures with and without maintenance at a starting level of 15% soil moisture (15-day study).

Soil temp. °C	g dry weight	g new growth	Transpiration ml/g dry weight	Transpiration ml/g new growth
		15% soil moisture maintained		
10	.38	.32	95	113
18	.45	.39	255	289
35	.25	.19	260	343
		15% soil moisture allowed to become depleted		
10	1.55	1.49	36	110
18	1.28	1.22	24	40
35	.16	0.10	166	265

A. tridentata grows poorly at a root temperature of 35°C (see page 95). At this temperature, however, the transpiration rate was very high (Table 4). Transpirational water loss by new growth was much higher for this species than for the other three especially at the highest soil temperature. This species lost resistance to water movement as soil temperature was increased. This may be related to its failure to grow in hot deserts.

Table 4. Water use by A. tridentata at 3 soil temperatures with maintenance of a starting level of 15% soil moisture (18 days).

Soil temp. °C	g dry weight	g new growth	Transpiration ml/g dry weight	Transpiration ml/g new growth
10	.42	.20	261	705
18	.61	.39	237	654
35	.30	.07	1320	5640

Summary

Seedlings of 4 desert plant species *Salsola pestifera*, A. Nels., *Sporobolus airoides* (Torr.) Torr., *Atriplex lentiformis* (Torr.) Wats., and *Artemisia tridentata* Nutt. were grown in Yolo loam soil at root temperatures of 10, 18, or 35°C. Two soil moisture systems were used for the first three and one for the last. Dry matter production increased for increasing soil temperature for *S. pestifera* between 21 and 35°C and for the others between 10 and 18°C. Soil temperature at 35°C greatly decreased that for *A. tridentata*. Transpirational water use efficiency measured either as ml/g new growth or ml/g dry weight increased for some species as soil moisture was decreased and at the higher temperature. For *A. tridentata*, however, the high temperature resulted in loss of resistance to water movement.

INTERCEPTION OF RAIN BY FOLIAGE OF DESERT SHRUBS

If some plant species native to desert areas are able to "collect" rainfall and channel it down their stems so that it enters the soil at the base of the shoot that plant may have ecological advantage for two possible reasons. One is that sparce summer rains may enter soil in sufficient volume (but in a smaller area) to penetrate into the root zone with the foliage and stems of the plant acting like a funnel; the other reason is the rain enters the soil at a location where it is most likely to penetrate into the soil rather than move away as run off.

The periphery of the branches of trees or shrubs is often considered as a "drip line" which diverts rain water to the outside of the plant. At least for one tree species the rain reaching the tree is funneled from leaves to branches and down the tree trunk (Haas, 1947). It was wondered if some desert shrub species behaved similarly.

Litter generally accumulates under native shrubs and shrub clumps and its partial decomposition on the soil surface usually makes soil much more permeable to water. It can be expected that rain water entering soil near the center of accumulated litter would be more likely to penetrate soil than rain not striking the area influenced by the litter.

A Hudson sprayer was used to spray droplets of water onto shrub species to simulate rain. For *Larrea divaricata* the simulated rain essentially all moved down the stems of the plant and entered the soil in one spot. *L. divaricata* is a species that responds to summer rain. Simulated rain on *Ephedra nevadensis* moved mostly down stems. With *Franseria dumosa* most of the simulated rain dripped through the plant without being funneled to a point location. The simulated rain dripped down the waxy leaves of *Yucca schidigera* but ran off the lower dead leaves which spread the rain as it reached the soil so that it did not reach a common point. This idea needs further experimentation to determine its ecological importance.

GERMINATION AND SEEDLING GROWTH OF COLEOGYNE RAMOSISSIMA AS INFLUENCED BY TEMPERATURE

According to a research report concerning shrub species of the Great Basin-Mojave Desert regions (Wallace et al., 1970), seed of twelve species studied germinated directly in vermiculite at glasshouse temperatures of about 25°C. Seed of the single remaining species studied, Coleogyne ramosissima, did not germinate at that temperature, but did so at 4°C. Whereas the former species appear to possess no chilling requirement for breaking of seed dormancy, it is suggested that the later may. This hypothesis was tested.

Seed of C. ramosissima was collected in Rock Valley in the Nevada Test Site in June of 1969. Seed of several plants in one general area was composited.

On January 25, 1970 a quantity of seed was soaked 5 minutes in 10% Purex and then washed. Twenty-five seed were placed between layers of moist filter paper in each of six petri dishes and, after 24 hours at room temperature, one dish was put into each of six controlled-temperature boxes maintained at 32, 24, 16, 10, 0, and -10°C, respectively. No dish was exposed to light. Seeds were considered germinated when the radicles had elongated to 5 mm.

By February 12 seeds were germinating in the dish at 10°C only, indicating the preference of a cool temperature but a necessity of little or no actual chilling.

At this time the seed of each dish was planted in #3 (fine) zonolite in 12 cm-clay pots, and all pots were maintained at 10°C to observe the effect of the previous temperatures upon seed emergence at what appeared to be an optimal temperature for germination (10°C).

The rate of seed germination or emergence at the specified temperature is given in Table 1.

Table 1. Germination or emergence of seed of C. ramosissima as affected by temperature.

Temperature, from Jan. 25 to Feb. 12	Germinations per dish of 25 seed as of Feb. 12	All seeds changed to 10°C on Feb. 12 Emerged seedlings per 25 seed		
		Feb. 19	Feb. 25	Mar. 16
°C	no.	no.	no.	no.
32	0	2	10	17
24	0	2	6	18
16	0	3	6	15
10	5	20	22	22
0	0	0	1	18
-10	0	0	3	14

The results indicate that the most efficient germination temperature is probably near 10°C, but that considerably higher or lower temperatures previous to the application of that temperature appear to have no particularly adverse effects such as inducing dormancy or decreasing viability. They also tend to confirm previous experience with germination of *C. ramosissima* in vermiculite, where 10° C had given consistantly good germination whereas at regular glasshouse temperatures germination had been erratic and generally poor.

A study of growth of seedlings of *C. ramosissima* at various temperatures was begun December 10, 1969. Five seed were placed in each of five 10 cm-clay pots in a mixture of one part pumice and one part Yolo loam, and the pots were placed in a chamber at 10° C for germination. By late January the seedlings had become well established, and at this time four pots were placed in chambers at 10, 16, 24, and 32° C, respectively, and the fifth placed in the glasshouse where temperatures normally varied daily from 18 to 28° C. The seedlings were watered and fertilized as necessary, and on April 20, 1970, the tops were harvested, measured, dried, and weighed. The growth results are given in Table 2.

Table 2. Effect of temperature on growth of *C. ramosissima* seedlings.

Temp.	Light*	Number of plants	Mean height	Mean weight	Compactness of seedlings
°C	f.c.x10^3		mm	mg	mg/mm
10	2.4	5	9	53	5.6
16	2.4	5	29	125	4.3
24	2.4	4	85	248	2.9
32	2.4	4	48	52	1.1
18-28	5.1	5	66	285	4.3

*Averaged over the time period 8 a.m. to 5 p.m. on sunny days which were typical during this experiment.

Whereas seed germination had been most successful at a low temperature, optimal growth of seedlings on the weight basis required a higher temperature, somewhere near 24° C. With the amount of light in the temperature chambers the seedlings elongated considerably as the temperature increased from 10 to 24° C, and over the range 10 to 32° C the seedlings became less compact and dense. Best seedling growth was obtained for those seedlings in the glasshouse with a fluctuating temperature and considerably more light. The additional light appeared to increase compactness of seedlings.

R. T. Ashcroft is the principal author of this report.

SOME PRELIMINARY CO_2 AND H_2O EXCHANGE STUDIES WITH NULL-POINT GAS EXCHANGE EQUIPMENT WITH SPECIES NATIVE TO THE NEVADA TEST SITE

A null-point gas exchange instrument (Koller, 1970; Koller and Samish, 1964; Whiteman and Koller, 1964; Walker, 1970) has been set up in this laboratory with automatic controls.

An improved version of the Null-point Compensating System to measure photosynthesis, respiration, and transpiration of plants was developed recently by Koller (1970). A modification of the original servo control unit for this system has been described by Mork et al. (in press).

The apparatus consists of three units: (1) a plant chamber; (2) a temperature control unit; (3) a null-point compensating unit.

(1) The plant chamber is a modified Siemens Gas-exchange, transparent assimilation chamber.

(2) The temperature control unit has controls for chamber air temperature (Siemens temperature controller with power supply) and for dew-point temperature of two thermo-electric water absorbers in the compensating system.

(3) The null-point compensating unit includes (a) a sampling loop; (b) a humidity-compensating loop; (c) a CO_2-compensating branch; and (d) an improved feedback control.

This system has the capability of making accurate, continuous measurements of vapor fluxes under constant atmospheric conditions and recording the rate of compensation required to maintain those constant conditions.

The principle of operation is based on prevention of any change in atmospheric composition in the chamber as a result of measurement. This is achieved in the case of transpiration by drying the appropriate proportion of the chamber atmosphere, in the case of photosynthesis by supply of CO_2-enriched air, and in the case of respiration by supply of CO_2-free air. The first case involves no volume change in the system, while the two others involve displacement of an equivalent volume of air from the system. The activity of the plant is measured by determining the rate of compensation (drying, CO_2 supplied or removed per unit time).

Some examples of preliminary studies made with the instrument follow:

Three plant species grown in soil were irrigated with a full nutrient solution plus 0, 50, 100, 200, or 400 me per liter NaCl. The use of the full nutrient solution was so that the sodium would not replace all of the exchangeable potassium, calcium, and magnesium in the soil. Data obtained (Table 1) indicated decreasing photosynthesis and transpiration for each species for 200 and 400 me per liter NaCl. The *Artemisia tridentata* eventually died at these two levels of NaCl. The data were obtained after about 2 months of treatment. The compensation period (Tregunna and Downton, 1967) seemed to increase for two species at the highest NaCl level. The *Atriplex* species and *Salsola pestifera* seem to have the C-4 dicarboxylic acid pathway for photosynthesis (Hatch and Slack, 1966; Slack and Hatch, 1967; Black et al., 1969).

During the period of May 19 to July 8, 1970 individual plants and branches of plants of several species were tested for net CO_2 uptake and net H_2O release using the equipment described above. The results are in Table 2. The data were collected at different hours of the day and may not be totally comparable. The soil moisture in no cases was limiting and was near the zero bar level during the tests. The first five species in the list appear to have the C-4 dicarboxylic acid pathway of photosynthesis (see above). There seemed to be large species differences in CO_2 and H_2O exchange.

Table 1. Transpiration and photosynthesis vs salinity (dry weight basis).

Species	Photosynthesis (mg CO_2/gm/min)	Transpiration (mg H_2O/mg/min)	Compensation Point (ppm CO_2)
Atriplex canescens			
0 me/l NaCl	0.298	21.1	5
50 me/l	0.297	22.2	6
100 me/l	0.140	6.7	4
200 me/l	0.163	8.7	4
400 me/l	0.089	4.7	5
Atriplex confertifolia			
0 me/l NaCl	0.780	5.1	4
50 me/l	0.129	7.4	4
100 me/l	0.119	5.7	6
200 me/l	0.042	2.6	4
400 me/l	0.039	1.8	~100
Artemisia tridentata			
0 me/l NaCl	0.075	5.9	46
50 me/l	0.041	3.1	56
100 me/l	0.060	4.4	47
200 me/l	0.037	1.4	<70
400 me/l	0.018	1.4	–

Table 2. CO_2 and H_2O exchange rates for several species of plants native to the Nevada Test Site (dry weight basis).

Species	Net CO_2 (mg CO_2/gm/hr)	Net H_2O (g H_2O/gm/hr)	25° Compensation point (ppm CO_2)
Atriplex canescens	15	0.86	5
Atriplex confertifolia	5.6	0.32	4
Atriplex hymenelytra	21	1.81	5
Atriplex lentiformis	15	1.95	11
Salsola pestifera	22	2.35	4
Lycium andersonii	37	5.40	49
Lycium pallidum	35	3.74	39
Lycium shockleyi	30	4.44	44
Franseria dumosa	33	3.89	39
Encelia virginensis	17	1.93	39
Artemisia tridentata	3.7	0.28	50
Coleogyne ramosissima	7.3	0.54	55
Prunus fasciculata	—	—	43
Selinocarpus diffusus	23	2.22	51
Larrea divaricata	1.9	0.13	66

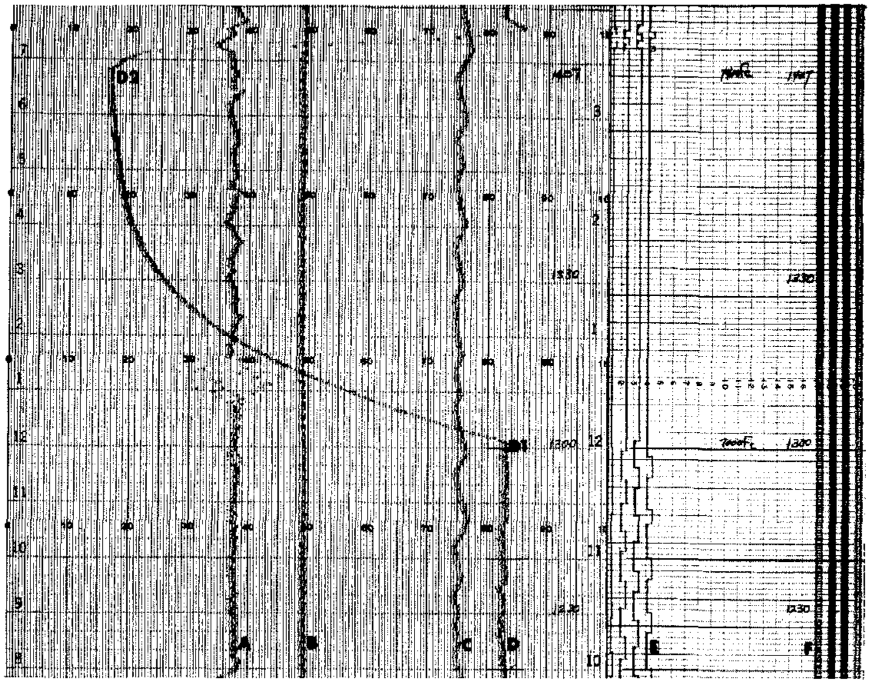
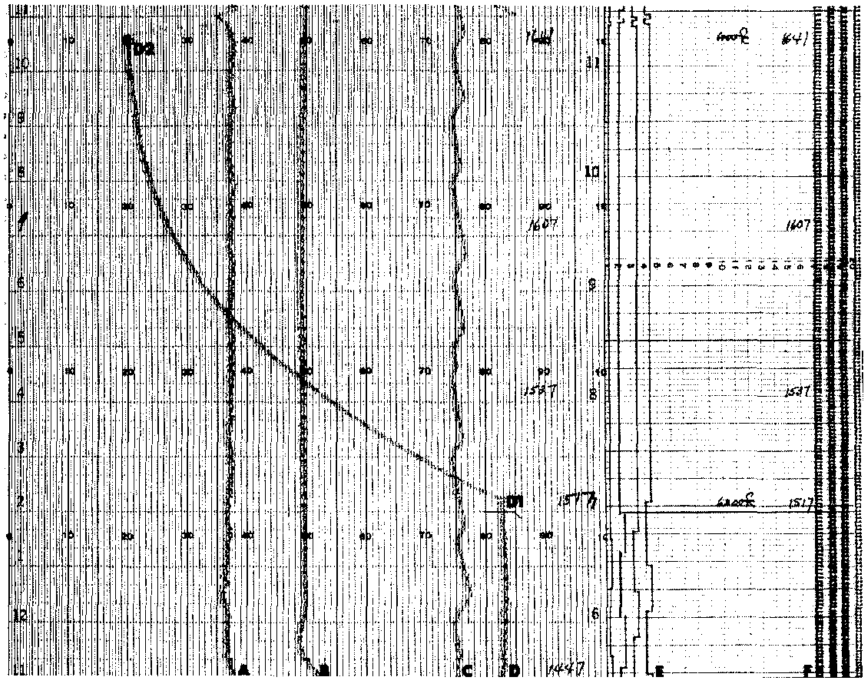


Figure 1. Lycium andersonii. Photosynthesis, transpiration and compensation point, early afternoon, 1 July 1970 (see text).

Figure 2. Lycium shockleyi. Photosynthesis, transpiration and compensation point, late afternoon, 1 July 1970 (see text).



Data obtained with *Artemisia tridentata* under stress indicate that it can remove soil moisture effectively above tensions of 60 bars (Table 3). When tensions reached about 36 bars, transpiration rates began dropping off rapidly. Net CO_2 assimilation begins decreasing at about 46 bars and reaches very low values at about 46 to 55 bars. Transpiration rates dropped to about zero in the soil tension range of 60 to 70 bars. If irrigated at this point the plant recovers completely. In these studies with confined root systems, the plants died after about a week under conditions where transpiration dropped to approximately zero.

These studies and continuing similar studies will contribute to an understanding of physiological parameters influencing plant populations and distributions at the Nevada Test Site.

Table 3. Transpiration and photosynthesis of *Artemisia tridentata* as a function of soil moisture under stressed and non-stressed conditions.

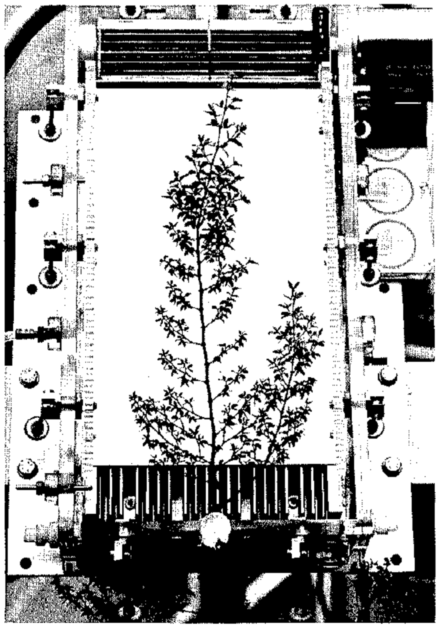
Days after*	Photosynthesis (mg CO_2 per min)		Transpiration (mg H_2O per min)		% soil moisture for stress treatment	Bars tension under stress
	20% moisture	under stress	20% moisture	under stress		
1	3.34	1.73	35.1	21.0	20.3	0.0
3	3.02	1.95	28.5	23.3	20.2	0.0
6	2.25	1.55	29.6	22.0	19.9	0.3
8	3.02	2.05	27.4	20.5	15.7	18.8
10	3.34	2.60	40.2	22.1	13.8	24.4
13	3.02	2.05	31.3	27.5	11.0	36.0
15	3.02	1.95	35.8	17.5	8.5	46.0
17	2.76	1.13	32.7	11.6	6.6	55.8
20	2.62	0.73	31.8	8.5	5.4	59.2
22	2.62	0.38	36.4	7.0	4.6	61.6
24	2.00	—	35.7	4.2	4.0	64.0

*Days after start of study when both treatments were uniformly moist.

Examples of typical data on photosynthesis, transpiration, and compensation point on two desert shrubs are shown in Figures 1 and 2. Each trace is identified by a letter designation as follows: A, water vapor or humidity; B, chamber temperature; C, bath temperature; D, CO_2 concentration; D1, point at which CO_2 supply was turned off; D2, approximate compensation point; E, rate of CO_2 addition; F, rate of water vapor removal. In each case the set-point dial readings (about 40 mv and 80 mv for humidity and CO_2, respectively) represent the desired concentrations of water vapor and CO_2 in the chamber. Reference to the respective humidity sensor graph (Mork et al. in press) and the concentration graph (Mork et al. in press) show the relative humidity to be about 28% (for a dial reading of 37) and the CO_2 concentration to be about 325 ppm (for a dial reading of 83). The ordinate of the strip-chart is time.

The Esterline Angus recorder charts on the right of the figures show the following data for the two desert shrubs: *Lycium andersonii* (Figure 1) used 31 mg of CO_2 and released 4.3 g of water vapor per gram of dry leaf tissue per hour; compensation point 45 ppm. *Lycium shockleyi* (Figure 2) used 24.8 mg CO_2 and released 4.9 g of water vapor per g of dry leaf tissue per

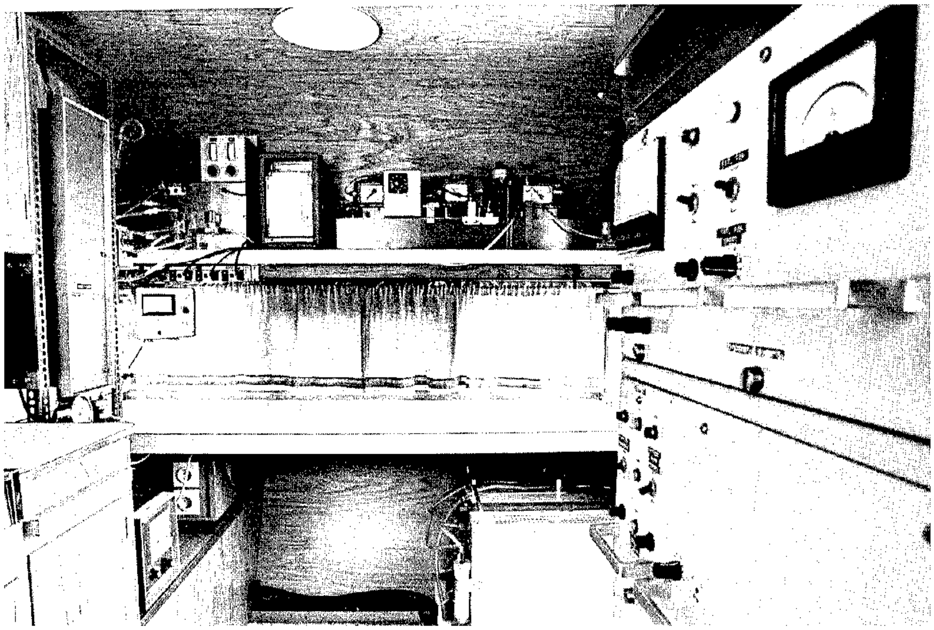
Figure 3. Plant chamber showing branch of Larrea divaricata in place for study.



hour; compensation point 54 ppm.

Photographs of some of the parts of the Null-point Compensating System are shown in Figures 3 and 4.

Figure 4. Portions of Null-point Compensation System mounted in trailer for field studies.



FLOOD DAMAGE AT THE NEVADA TEST SITE AND AMARGOSA VALLEY IN 1969

Rainfall during January and February 1969 in southern Nevada greatly exceeded normal amounts (Table 1). Because desert soils often have a low water holding capacity and/or slow rate of infiltration, most high level rainfall is surface runoff. In addition plant populations are not adequate to hold the soil in place against rapid water movement. For these reasons, a great deal of flood and water damage resulted from the high amount of rainfall in early 1969. Such infrequent and high intensity rains are of great ecological consequence in terms of biota and land forms.

Table 1. Total rainfall (cm) for January and February at various locations on and near the Nevada Test Site.

Location	1965	1966	1967	1968	1969
Amargosa Valley (Schultz Ranch)	0.8	1.2	0.8	3.4	8.1
Rock Valley	0.6	2.5	3.3	3.2	17.1
Desert Rock	0.5	2.1	3.1	2.5	14.8
Cane Springs	0.9	2.1	4.4	4.2	22.9
Tippipah Springs	0.5	1.0	1.5	6.0	28.1
Public Health Farm	0.3	1.4	1.1	5.7	16.4

Figure 1. The vehicle just happened to be in the wrong spot when the recent storm sent flood waters rushing down desert washes, wrecking roads and stopping traffic. The driver was able to get away safely. (Courtesy of N. T. S. News)

Figure 2. View of Schultz Ranch (surrounded by trees) looking approximately southeast. The straight line which starts at the lower right is an old railroad bed. Water came from the north (bottom of picture). This is a new stream channel in what was level creosotebush desert.

Figure 3. View through a solid-row planting of tamarisk trees showing exposed roots. The tree on the left was almost pushed over. This row of trees slowed the flood water and much of the silt and fine sand was dropped here.

In many locations during the January and February 1969 rains, asphalt roads were washed out or undercut so as to be impassable. Many unsurfaced roads which were not protected became temporary stream beds, exposing large rocks in some places and in other places filling up with fine sand and silt.

Established stream beds were inadequate for the volume of water and the streams spread over widths of up to 45 meters. Many new stream beds developed. As the stream banks washed away, some plants were washed out, some had roots exposed, and some were buried in debris and gravel.

The accompanying Figures 1 - 5 with their captions illustrate the extent of damage in some areas.

Figure 4. The depth of this new wash can be seen in the cut bank. In the center are chunks of asphalt washed off the road. Such storms and resulting runoff have great consequences in recycling of radionuclides.

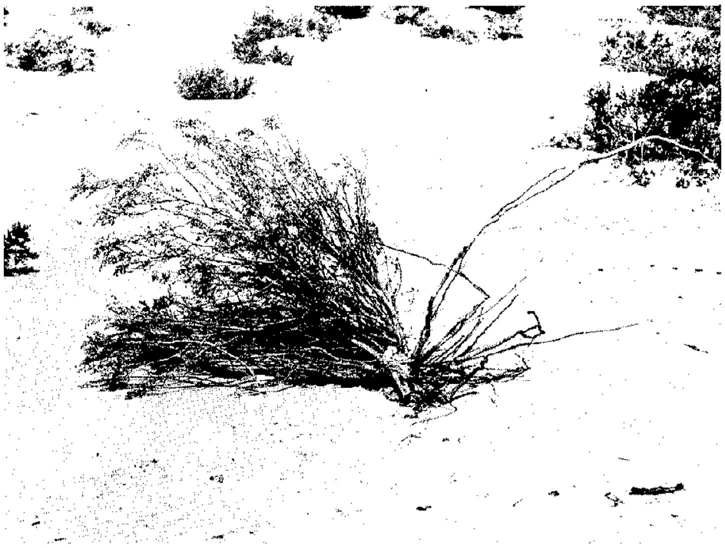


Figure 5. A large Larrea divaricata which was uprooted by flood water. Enough root was reburied in silt to permit some new leaf growth.

PRELIMINARY STUDIES ON NITROGEN CYCLING

Nitrogen is believed to be one of the most important limiting factors in primary productivity in desert ecosystems. Relatively little is known of nitrogen use and input for the system under study. Shields and Drouet (1962) reported the presence of blue-green algae in several of the soils of the Nevada Test Site and these algae are capable of biological nitrogen fixation. An accurate assessment of the nitrogen cycle must await detailed studies of nitrogen fixation in the soils involved and of decomposition of the materials produced.

Experimental Results

A small mixed shrub clump in Mercury Valley was selected as one study site. It was near a wash and subject to flood in heavy rain. Its dimensions were 80 cm by 80 cm and approximately 0.64 m^2. The boundary of the sample area extended about one-half the distance to other shrub clumps. The site contained five different species of shrubs (Table 1). There were one of each except several of Krameria parvifolia. No annual plants were present at the time of sampling. The plants were beginning to show new growth on the sampling date of March 15, 1967. The tops of plants were removed and cut up for drying and grinding. The soil in the entire plot was excavated to a depth of 45 cm so that the roots could be removed. The roots also were washed and cut up for drying and grinding. Soil samples were taken representing A_0, 0-15, 15-30, 30-45 cm depth, both directly under the shrubs and also in the open area on which no shrubs grew.

In Table 1 are weights and total nitrogen contents for the five shrubs. The samples were assayed with a Coleman nitrogen analyzer.

Table 1. Dry weights and nitrogen contents of the shrubs present in the 0.64 m^2 area that was sampled.

	Above ground dimension cm (h) x cm x cm	Shoot wt g	Root wt g	Total N Shoot % of dry wt	Total N Root % of dry wt
Larrea divaricata	50 x 30 x 50	68	32	1.20	2.04
Eurotia lanata	30 x 20 x 20	20	2	1.17	1.54
Franseria dumosa	30 x 40 x 40	259	150	1.21	1.03
Krameria parvifolia	15 x 30 x 30	183	103	1.19	0.78
Lycium andersonii	30 x 50 x 50	415	118	1.33	1.65
Weighted means		945	405	1.25	1.34

Soil samples were also analyzed with the Coleman nitrogen analyzer (Table 2); one-half g samples were used. Nitrate nitrogen was determined on the samples also by the phenoldisulfonic acid method with water extracts (Table 2).

The results in Table 2 can be summarized to indicate that the soil organic matter and litter contains about 770 to 2200 kg N/ha (1050 kg/ha mean). There was between 33 and 55 kg nitrogen/ha in the plant produce. Very similar results were obtained by Garcia-Moya and McKell (1970). There was about 1 kg

Table 2. Nitrogen and carbon contents of the soil from the Mercury test plot on the oven dry soil basis.

Soil and depth, cm	Total N ppm	Organic C %	C/N	NO_3-N ppm
Near shrubs, A_o	1540	2.50	16.2	2.4
Near shrubs, 0-15 deep	585	0.56	9.6	1.4
Near shrubs, 15-30 deep	489	0.45	9.2	0.7
Near shrubs, 30-45 deep	384	0.36	9.4	0.6
Away from shrubs, 0-15 deep	295	0.32	10.8	0.5
Away from shrubs, 15-30 deep	299	0.22	9.2	0.5
Away from shrubs, 30-45 deep	252	0.28	11.1	0.3

per hectare of nitrate nitrogen. Without accurate data for the new growth production for a given year we assumed that the new growth was about 20% of the standing biomass as is known to occur for a tree species and we further assumed that the total amount of nitrogen in the new growth was equal to about 20% of that in the shrub (Cameron et al., 1954). This would mean from 7 to 9 kg of nitrogen actually used per year on the per hectare basis. This estimate could be in error easily by 50% either way. Since about 2% of the organic nitrogen in an average soil can be mineralized in a year (Millar et al., 1965), the soil organic matter that has accumulated in this desert environment could deliver approximately 21 kg nitrogen per hectare per year on this basis of calculation. This supply of available nitrogen (21 kg) vs that actually needed (7 to 9 kg) would more than adequately meet the requirements of the primary production without nitrogen deficiency if assumptions either that the soil is 100% occupied by roots or that any mineralized nitrogen is available to plants by the process of mass flow (Barber et al., 1963) are valid. Nitrogen then may not be a limiting factor in this system. The use of irrigation water, however, to increase primary productivity may make nitrogen limiting. Annual plants did respond to nitrogen, however, in plots near the same area. In May of 1969, following a nitrogen treatment in 1967, the annual plants in Rock Valley responded to the nitrogen treatments, but the shrubs did not (Table 3). The annuals were in the open areas between the shrubs where soil organic matter had not accumulated.

Table 3. Dry weight of *Chaenactis fremontii* from plots fertilized with nitrogen and not fertilized with nitrogen.

Treatment NH_4NO_3 kg N/ha	Dry wt per plant g
0	0.19
100	2.03

Similar plant excavation studies have been made in an *Artemisia tridentata* community. No other shrubs were present in the site studied. An area of one m^2 was selected in the Pahute Mesa area on May 8, 1968. The plant material was divided into new leaves, living stems, dead stems, roots and litter. Soil samples were taken to represent 0 to 2.5, 2.5 to 7.5, 7.5 to 15, and 30 to 45 cm depths. Data obtained are given in Tables 4 and 5. Of the 239 kg of nitrogen in the plant material on the per hectare basis, 22 kg were in new leaves. If approximately similar amounts were needed for new growth of stems and also of roots (over estimated), some 55 to 65 kg would be needed annually for the crop. The approximate seven kg per hectare represented as nitrate nitrogen in the soil would be a small part only of the estimated need. If 2%, however, of the total soil organic nitrogen (5000 kg/hectare) were made available in a given year, about 100 kg would be available annually. Since this exceeds the need by approximately 50% we can postulate that the mineral nitrogen input into the system is real (perhaps by microbiol symbiotic biosynthesis—see page 352) and that perhaps mineral nitrogen is being leached from the system to ground waters.

Table 4. Nitrogen contents of plant materials from an Artemisia tridentata community at Pahute Mesa.

	N content %	Dry wt plants kg/ha	N kg/ha
New leaves	1.39	1590	22.0
Living stems	0.69	9460	65.2
Old dead stems	0.46	8800	40.4
Roots	0.58	5300	30.8
Litter	1.01	7980	80.6
Totals		33130	239.0

Table 5. Nitrogen contents of soil from the Artemisia tridentata community at Pahute Mesa.

Depth cm	N %	N kg/ha	Nitrate-N ppm	Nitrate-N kg/ha
0-2.5	0.212	777	4.35	1.60
2.5-7.5	0.123	902	1.58	1.16
7.5-15	0.079	870	0.76	.84
15-30	0.065	1430	0.68	1.41
30-45	0.048	1056	0.55	1.21
Totals		5035		6.22

Summary

Analyses of soils and of the standing crop in a Larrea-Franseria community and in an Artemisia community at the Nevada Test Site indicate that nitrogen is not a limiting factor under usual conditions of shrub growth in those communities. It was for annuals growing between shrub clumps, however. The soil organic matter in the Larrea-Franseria community contained about 2200 kg nitrogen per hectare while the standing crops contained about 45 kg per hectare and of this about 10 kg is needed annually for the new growth. Since the soil organic matter would supply approximately 21 kg of nitrogen, nitrogen would not be deficient nor would atmospheric nitrogen need to be fixed to main-

tain balance on a short-time basis. In the Artemisia community 239 kg nitrogen per hectare was in the standing crop with an estimated 55 to 65 kg needed annually. The soil organic matter contained over 5000 kg of nitrogen per hectare. This could deliver around 100 kg to plant growth annually. It could be expected that some nitrogen could be leached from the system each year if atmospheric nitrogen were fixed and if the system were in steady state.

PRELIMINARY ESTIMATION OF SOME ASPECTS OF PHOSPHORUS CYCLING IN TWO LOCATIONS AT THE NEVADA TEST SITE

The two sites used in this preliminary estimation are those used for the nitrogen estimation (see page 339). Because so many agricultural crops respond to phosphorus under irrigation when grown on desert soils in the western United States, it was suspected that phosphorus may be one of the limiting factors in primary productivity in ecosystems at the Nevada Test Site.

Data for phosphorus contents of shoots and roots for the perennial plant species involved in the site at Mercury Valley are in Table 1. For these plants the amount of phosphorus involved in the standing crop was about 45 kg per hectare within the shrub clump. This involved the area in which the shrubs grew and did not include the bare areas (ground cover for shrubs was about 20%). Assuming that up to half this much would be needed for annual new growth because of turnover due to leaf abscission and flower and seed production, about 25 kg per hectare would need to be accumulated from the soil annually. The amount needed for the annual plants likely would be less because the primary productivity for annual plants is generally less than for the perennial plants (see page 230). In any event the phosphorus needs for plants in this system may be somewhere around 30 kg per hectare per year (6 kg per hectare per year considering 20% ground cover).

Table 1. Phosphorus contents of perennial plants excavated from a 0.64 meter^2 site in Mercury Valley.

	Dry weight		P		P			P
	shoot	root	shoot	root	shoot	root	total	
	g	g	% of dry wt		g/0.64 m^2			kg/ha
Larrea divaricata	68	32	0.16	0.07	0.108	0.022	0.130	2.03
Eurotia lanata	20	2	0.22	0.09	0.044	0.002	0.046	0.72
Franseria dumosa	259	150	0.30	0.19	0.777	0.285	1.062	16.59
Krameria parvifolia	183	103	0.34	0.26	0.622	0.267	0.889	13.89
Lycium andersonii	415	118	0.18	0.14	0.747	0.165	0.912	14.25
								47.48*

*In the clump. If ground cover is 20% then the amount of phosphorus in kg per hectare = 47.48 × .2 = 9.5 kg per hectare.

The soils in this area have been examined for bicarbonate-soluble phosphorus (Olsen et al., 1954). In an earlier test we had found 5 kg per hectare of available phosphorus in the first 5 cm of soil. Lower horizons contained about 1 kg per hectare for each 5 cm of soil. Roots occupy about 40 cm of soil so that about 12 kg soluble phosphorus would be available per hectare. In another sample there were 1.3 kg per hectare for 0 to 15 cm, 0.4 kg per hectare for 15 to 27 cm, 0.5 for 27 to 44 cm, and 1.3 for 44 to 150 cm. This totals 4.5 kg per hectare and represents the ground area occupied by the shrub clump (approximately 20% of the total). The area outside the shrub clump which represented the other 80% had 2.1 kg per hectare soluble phosphorus to the 150 cm depth. This could support the few winter annuals only which grow in the open area. These values which indicate a mean of 2.6 kg per hectare seem to be less than the annual need of around 6 kg per hectare. It would appear, therefore, that under the conditions encountered that phosphorus supplies would be inadequate to maintain the amounts of production involved. Actually leaf contents for phosphorus (Table 1) are much like those for agronomic crops, i.e., they do not appear to be low. If production were greatly increased or if the cycle were upset by harvesting procedures (grazing for example), or if large amounts of leaching occurred, however, it appears that phosphorus stress may occur.

Data for phosphorus in the Artemisa tridentata stand at Pahute Mesa are in Table 2. The amount of phosphorus in the standing crop was around 60 kg per hectare and in an amount equal to twice that which was in the litter beneath the plants. If the transfer coefficient between these compartments is sufficiently large, the system could be maintained with no phosphorus stress. This may be unlikely since the amount of bicarbonate-soluble phosphorus amounted to about 15 kg per hectare in the A. tridentata shrub community. This is equal to about 20% of that in the litter and may be indicative of the annual transfer rate between the two compartments, i.e., about 20% per year. The 15 kg per hectare of phosphorus which was bicarbonate-soluble was similar in amount to that in the new leaves plus that in new branches and may represent closely the annual need for new phosphorus absorption. It would seem that the phosphorus status of the ecosystem may be quite fragile and may even be a limiting factor. The annual need appears to be about that which seems to be available.

Table 2. Phosphorus contents of plants and litter in an A. tridentata stand at Pahute Mesa.

	Plant material kg/ha	P % dry wt	P kg/ha
Leaves	1,750	0.307	5.37
New branches	10,500	0.080	8.40
Old branches	9,680	0.050	4.84
Roots	5,650	0.698	39.44
Litter	8,800	1.445	127.16
Total	36,380		185.21
Minus litter	27,580		58.05

The efficiency of available phosphorus absorption by roots is relatively low; 10 to 20% is common. If this is the case in ecosystems of the Nevada Test Site, it may be a reasonable conclusion that phosphorus is limiting or at least very near a limiting factor.

Tiedemann and Klemmedson (1970) found in Arizona that phosphorus was limiting for at least one species of grass growing in areas between mesquite trees. It may be that phosphorus is also limiting at the Nevada Test Site for at least some species. The total phosphorus content of the soil below the litter from the Pahute Mesa site according to the nitric-perchloric acid digestion procedures was 195 ppm; this is a low content and indicative of potential stress.

EFFECT OF BORON LEVELS ON TWO DIFFERENT PLANT SPECIES WHICH OFTEN GROW IN SOILS HIGH IN BORON

Franseria dumosa and Atriplex hymenelytra tend to grow in soils which are high in boron. Both are very common in areas of Death Valley, California. F. dumosa is also very prevalent in the southern portion of the Nevada Test Site where A. hymenelytra is present in small quantities only (Beatley, 1969). Boron contents of leaves of these species which were collected from the field indicate that F. dumosa accumulated boron in moderate quantities but that A. hymenelytra had variable quantities of it in leaves (see pages 156 and 185).

Chatterton et al. (1969, 1970) grew Atriplex polycarpa in solution culture and found that the tolerance of this species to boron is related to its ability to absorb relatively little of it from the nutrient substrate. This species also grows abundantly in places like Death Valley. The present studies indicate that A. hymenelytra and F. dumosa to a lesser extent have the same ability.

Materials and Methods

F. dumosa seedlings 2 months old were transferred from vermiculite to 1800 ml modified Hoagland nutrient solution with added boron levels of 0.0, 0.1, 2, 5, 10, 20, 50, 100 ppm. The plants were grown for 25 days in these solutions without change. The plants were then divided into roots, stems, leaves, washed in 1/10 N HCl and deionized water, dried, weighed, ground and prepared for spectrographic analyses. The experiment was set up in duplicate.

A. hymenelytra cuttings (see page 173) which had been rooted in soil 3 months previously were washed from the soil and placed into 1800-ml pots in nutrient solution without added boron. After 2½ weeks the nutrient solutions were changed and boron levels of 0.0, 0.1, 2, 5, 10, 20, 50, and 100 ppm were added to the plants with duplicates of each treatment. The solutions were changed after 25 days and the plants were grown without change of nutrient solution for another 40 days. The plants were then separated into roots, old stems, new stems, and leaves. They were otherwise handled as were the F. dumosa seedlings.

Experimental Results

Yields of the F. dumosa plants are in Table 1. The 0.0 level might have resulted in some growth reduction, but there were no special deficiency symptoms on the leaves of the plants. Maximum growth was obtained for between 2 and 10 ppm boron although the data were somewhat erratic. Levels of 50 and 100 ppm boron caused growth depression although special toxicity symptoms were absent. Results of analyses in Table 2 indicate that the boron contents were much lower for given levels of boron than for some other plant species such as avocado where 2 ppm in external solutions can result in several hundred ppm in leaves. Boron contents of the F. dumosa plants increased considerably for 10, 20, 50, and 100 ppm boron and most of the boron was found in the leaves. Oertli and Richardson (1970) have suggested that boron is moved under influence of the transpirational stream; hence, the present results with boron being mostly in leaves could be due to that phenomenon. Boron contents of

Table 1. Yields of F. dumosa plants grown in solution culture at different boron levels.

B, level ppm	Roots	Stems	Leaves	Whole plant
	Yield, mg dry weight per plant			
0.0	184	543	735	1462
0.1	166	884	1096	2146
2	236	1127	1470	2833
5	201	823	1127	2150
10	188	1170	1406	2764
20	144	727	963	1834
50	92	383	475	950
100	50	206	344	600

Means of duplicate plants.

Table 2. Boron contents of F. dumosa plants grown in solution culture at different boron levels.

B, level ppm	Roots	Stems	Leaves
	B, ppm of dry weight		
0.0	70	22	53
0.1	101	80	90
2	93	90	77
5	90	41	188
10	114	37	237
20	111	60	411
50	279	53	525
100	270	401	973

Means of duplicate plants.

roots were increased at high boron levels but not as much as in leaves.

The high boron levels seemed to influence potassium contents of roots of F. dumosa; the permeability resulted in loss of potassium from roots (Table 3.)

Yields of A. hymenelytra plants (Table 4) indicated progressive increases for up to 20 ppm boron in the nutrient solution. The slight yield decreases for 50 and 100 ppm were not associated with special toxicity symptoms. Boron contents (Table 5) were not greatly increased by high levels of boron; the species appeared to be highly resistant to uptake of boron as found by Chatterton et al. (1969, 1970) for A. polycarpa. It would seem that high levels of boron in the external medium would be necessary for normal nutrition of A. hymenelytra. The high level of boron had no effect on potassium contents of roots as was indicated with F. dumosa. The tolerance to boron of these 2 species is probably related to their ability to avoid its accumulation at high levels.

Summary

Two desert plant species were grown in solution culture with varying

Table 3. Potassium contents of F. dumosa plants grown in solution culture at different boron levels.

B, level ppm	Roots	Stems	Leaves
	% of dry weight		
0.0	6.47	6.33	6.52
0.1	8.11	8.10	7.66
2	6.72	7.81	8.26
5	9.19	9.48	6.71
10	7.37	11.46	6.43
20	6.12	9.24	8.81
50	2.47	3.93	4.47
100	1.07	5.07	5.52

Means of duplicate plants.

Table 4. Yields of A. hymenelytra plants grown in solution culture at different boron levels.

B, level ppm	Roots	Old stems	New stems	Leaves	Total
	Yield, mg dry weight per plant				
0.0	259	106	250	1290	1905
0.1	291	279	320	1863	2753
2	492	300	366	2176	3334
5	611	201	368	2431	3611
10	596	291	414	2661	3962
20	759	395	538	3403	5095
50	567	221	503	2777	4068
100	580	201	577	2623	3981

Means of duplicate plants.

Table 5. Boron contents of A. hymenelytra plants grown in solution culture at different boron levels.

B, level ppm	Roots	Old stems	New stems	Leaves
	B, ppm of dry weight			
0.0	41	28	32	31
0.1	39	23	30	22
2	40	27	42	57
5	50	44	39	70
10	57	81	46	116
20	48	52	52	156
50	57	70	71	154
100	61	103	92	155

Means of duplicate plants.

levels of boron. Both appeared to be very resistant to accumulation of large amounts of boron but F. dumosa accumulated moderately high amounts of it at levels of ten or more ppm in the nutrient solution. Growth reduction was indicated for this species at 50 and 100 ppm boron in the nutrient solution. The high levels of boron resulted in decreased potassium levels in roots for this species. Growth seemed to increase for A. hymenelytra up to a level of 20 ppm boron in the nutrient solution but leaf contents at this level were only 156 ppm of dry weight. Higher levels did not further increase boron contents of leaves. The distribution of both of these species in the desert is probably related to their ability to accumulate small amounts of boron in the presence of large amounts of boron in the soil.

RESPONSE OF MOJAVE DESERT VEGETATION TO NITROGEN FERTILIZER AND SUPPLEMENTAL MOISTURE

Some results of studies at our field plots in Mercury Valley are reported elsewhere in this report. One of the main objectives in establishing these plots was to investigate the response of Mojave Desert vegetation to applied fertilizer amendments and supplemental moisture. The source of water applied by sprinkler irrigation was the reclaimed water impounded from the sewage processing system at Mercury, Nevada. Nitrogen and phosphorus fertilizers were applied onto the soil surface along with chelating amendments with and without iron. Inasmuch as the vegetation responded only to added nitrogen and moisture during the three growth seasons following treatment, we shall not report data from the other treatments.

Materials and Methods

Twenty-four paired plots, each 730$\underline{m}^2$ in area, were established on the south-facing slope in northern Mercury Valley near holding ponds for reclaimed sewage water. The quality of this water was marginal for irrigation purposes but it was the only source economically available for this study. Mineral contents and sodium-adsorption-ratio (S.A.R.) of this water were as follows:

Mineral	1967	1969
Ca (ppm)	18.44	12.5
Mg (ppm)	3.08	2.8
K (ppm)	16.00	16.5
Na (ppm)	263.0	266.3
Cl^- (me/l)	3.73	3.06
$SO_4^=$ (μmole/l)	862.0	765.7
S.A.R.	21.2	23.6

The algal contents varied considerably at different seasons of the year (70 to 100 mg/l).

The nitrogen treated plots received surface applications of NH_4NO_3 at levels equivalent to 100 and 200 kg of nitrogen per hectare. These treatments were added to plots in natural desert conditions and to plots periodically receiving supplemental moisture by overhead sprinkler irrigation to maintain soil moisture above a level of 5 per cent by weight. This was equivalent to from 25 to 30 cm of additional rainfall in an area which normally receives from 10 to 15 cm of rainfall annually. Plant and soil samples from treated and control areas were analyzed for total nitrogen contents by the Colemen Model 29A Nitrogen Analyzer II. Nitrate-nitrogen in soil was determined by the method of Chapman and Pratt (1961).

Results and Discussion

The greatest response from surface applications of nitrogen fertilizer came from winter annual plants with a two- to three-fold increase in standing crop biomass. There was, however, no significant increase in the number of plants per unit area. Some perennial plants showed visible growth response but the effect was less striking than with winter annuals. Growth was equally as good on plots fertilized with nitrogen at levels equivalent to 100 and 200 kg of nitrogen per hectare during the 3-year period of our observations indicating no beneficial influence from excess nitrogen input into the soil. Growth re-

Table 1. Nitrogen contents of samples of vegetation harvested in 1969 from plots treated with 0 and 100 kg of nitrogen per hectare.

Plant species	Nitrogen content in dry leaf tissues* Control plot %	Nitrogen content in dry leaf tissues* 100 kg N/ha %
Astragalus lentiginosus	3.33	3.07
Atriplex confertifolia	1.70	2.01
Chaenactis carphoclinia	1.38	1.68
Ephedra nevadensis	1.77	2.02
Eurotia lanata	1.66	2.35
Franseria dumosa	1.67	2.30
Grayia spinosa	1.71	1.90
Krameria parvifolia	1.47	2.05
Larrea divaricata	1.70	2.25
Lycium andersonii	2.10	2.23
Lycium pallidum	1.39	2.69
Mentzelia albicaulis	1.42	1.74

*Mean of 3 replicates of pooled leaf samples collected randomly.

Table 2. New shoot yield and nitrogen content of leaf tissues grown in plots fertilized with nitrogen with and without supplemental moisture (1970).

	Control		100 kg N/ha		200 kg N/ha	
Plant species	Yield* g	N %	Yield* g	N %	Yield g	N %
	Natural desert conditions					
Acamptopappus shockleyi	6.6	1.9	7.5	2.1	5.5	2.5
Ephedra nevadensis	4.1	2.3	4.4	2.8	4.2	2.8
Eurotia lanata	8.6	2.6	9.9	3.0	10.2	3.1
Franseria dumosa	8.0	3.6	9.3	3.9	7.4	3.9
Grayia spinosa	7.2	2.2	7.9	2.4	7.6	2.4
Krameria parvifolia	1.0	2.0	1.2	2.5	1.1	2.9
Larrea divaricata	2.9	2.8	2.8	4.1	2.9	4.3
Lycium andersonii	3.6	2.2	3.3	2.4	3.4	2.4
Means	5.4	2.5	5.8	2.9	5.3	3.0
	Supplemental moisture added					
Acamptopappus shockleyi	7.7	1.8	9.9	2.6	8.1	2.3
Ephedra nevadensis	3.0	1.8	4.1	2.7	3.6	2.6
Eurotia lanata	13.8	2.9	16.3	3.5	14.7	3.1
Franseria dumosa	9.0	3.8	8.0	3.4	8.3	4.1
Grayia spinosa	11.7	2.3	13.2	2.6	10.3	2.6
Krameria parvifolia	1.0	1.9	0.8	2.3	1.0	2.5
Larrea divaricata	3.2	2.7	2.6	3.3	2.9	3.1
Lycium andersonii	4.0	2.2	4.2	2.6	4.1	2.5
Means	6.7	2.5	7.4	2.9	6.6	2.9

*Data are means from three pooled samples consisting of 50 new shoots picked at random from 10 shrubs of each species in each plot.

sponse from supplemental moisture masked the increased growth response from added nitrogen. The nitrogen contents of plant samples harvested during the first season after nitrogen was applied in 1968 are shown in Table 1. In nearly all species tested the nitrogen contents were increased in leaf tissues grown on nitrogen-treated plots. Additional effects of nitrogen fertilization and supplemental moisture on desert vegetation are shown by data in Table 2. In natural dry plots no growth response to added nitrogen was measured except for *Eurotia lanata*. This same species along with *Grayia spinosa* responded significantly in plots receiving supplemental moisture, and all species listed showed growth response to added moisture with the exception of *Ephedra nevadensis*, *Krameria parvifolia*, and *Larrea divaricata*. Growth response from added moisture was greater than the response from added nitrogen fertilizer. For most species, however, the nitrogen treatments tended to increase the nitrogen contents in foliage. Our results indicate that very little increase in productivity can be gained from applying nitrogen to desert range areas unless there is also an input of supplemental moisture.

Summary

Field studies were made to determine the response of natural desert vegetation to nitrogen fertilization with and without supplemental moisture. The greatest response to nitrogen fertilizer occurred in winter annual species with a two- to three-fold increase in standing crop biomass. Among the perennial plants present, *Eurotia lanata* and *Grayia spinosa* showed the greatest growth response to added nitrogen. Plant growth on plots fertilized at levels of 100 and 200 kg of nitrogen per hectare indicated no increase in productivity from excess nitrogen added to a soil. Added nitrogen increased the total nitrogen content in the foliage of nearly all plants examined. The increased growth response from supplemental moisture masked the response of desert vegetation to added nitrogen fertilizer.

SYMBIOTIC NITROGEN FIXATION IN DESERT VEGETATION AND ITS RELATIONSHIP TO NITROGEN CYCLING

The nitrogen deficiency symptoms commonly seen in the foliage of cultivated crop plants seldom appear in the foliage of desert vegetation. Although nitrogen deficiency would be expected to occur in the desert environment, its symptomatic appearance might be masked by other limiting factors. For example, the seasonal moisture may be insufficient to sustain an amount of vegetation that could seriously deplete the available nitrogen in desert soils. Actually, the sparse stands of vegetation typical of most desert areas should require much less nitrogen than would be required of cultivated crop plants. Furthermore, most of the nitrogen utilized by plants is subsequently returned to desert soils through leaf fall and decomposition of litter. Leaching and erosion from rainfall probably account for the greatest loss of nitrogen from a given area in the desert; yet in some cases, that which is lost by run-off at one site might be compensated by run-in at another site.

Another factor to consider is the degree to which certain species of desert plants might fix atmospheric nitrogen through endophyte symbiosis of free-living microbial forms. This important life process has been the subject of several recent reviews (Becking, 1970; Bond, 1967; Jensen, 1965; Stewart, 1966 and 1967). With this in mind some seasonal surveys were made to see if nitrogen fixation could be detected in the root zone of desert plants by the acetylene reduction method.

Materials and Methods

These studies were conducted at the Nevada Test Site of the U.S. Atomic Energy Commission in southern Nevada. Most of this area lies in the transition zone between the Mojave and Great Basin Deserts where a number of plant species common to each of these deserts grow together in dominant or co-dominant association. Allred, Beck, and Jorgensen (1963) and Beatley (1965) have described the biotic communities of the Nevada Test Site.

Surveys were made at different seasons of the year to learn the extent to which nitrogen fixation might occur in the desert environment either from symbiotic microbial endophytes or from free-living forms. The acetylene reduction method was used to detect the presence of a nitrogen-fixation system without attempting to resolve its specific nature. This method is very sensitive and specific, and it has received broad application (Dilworth, 1966; Hardy et al., 1968; Koch and Evans, 1966; Schollhorn and Burris, 1967, and Stewart et al., 1967). Briefly, 50 g samples containing roots and soil, or soil alone, were taken from the root zone of plants growing in the field and placed in serum bottles. A few drops of water were added to moisten the soil if needed, and the samples were immediately purged with a gas mixture (80% argon, 20% oxygen, 0.04% CO_2) and then charged with a measured volume of acetylene. After selected incubation intervals, the samples were analyzed for the presence of ethylene by gas chromatography (Wheelco Flame Dectector). Control samples with Clostridium pasteurianum were run in conjunction with these field samples. Although the results of these preliminary surveys are qualitative, all verifications were made with multiple samples having from two to five replicates.

Experimental Results

Results of seasonal surveys on some prominent desert plant species in our study areas appear in Table 1. At no time was the presence of a nitrogen-fixation system detected in soil samples without roots; all positive results were with root-soil samples except for the lichens. Root nodules were prevalent on two of the legumes, *Astragalus lentiginosus* and *Lupinus argenteus*. We detected what were thought to be root nodules on *Artemisia tridentata* and *Krameria parvifolia*, but no intensive effort was made to examine whole-root systems for the presence of nodules or to isolate microbial endophytes; such work forms the basis for future investivations. As one might suspect, no evidence of a continuing fixation reaction was seen after the soil was depleted of its seasonal moisture with the onset of the hot, dry summer months. Negative results also were obtained in spot checks after some late summer and fall rains. Although these surveys did not identify the specific nature of a nitrogen-fixation reaction,

Table 1. Plant species surveyed for nitrogen fixation by the acetylene reduction method. An x indicates positive detection of the reaction in root-soil samples.

	Date of sample collection			
Plant Species	Dec. 9	Feb. 17	Apr. 16	June 12
Acamptopappus shockleyi				
Artemisia arbuscula				
Artemisia spinescens		x		
Artemisia tridentata		x	x	
Astragalus lentiginosus			x	x
Atriplex confertifolia				
Bromus rubens		x	x	
Coleogyne ramosissima		x		
Dalea fremontii		x	x	
Ephedra funerea				
Ephedra nevadensis				
Eriogonum inflatum				
Eurotia lanata				
Franseria dumosa				
Grayia spinosa				
Hilaria rigida				
Hymenoclea salsola		x		
Kochia americana				
Krameria parvifolia		x		
Larrea divaricata				
Lepidium fremontii				
Lichens (not identified)		x		
Lupinus argenteus			x	x
Lycium andersonii				
Lycium pallidum				
Lycium shockleyi				
Oryzopsis hymenoides				
Sphaeralcea ambigua				
Tetradymia canescens		x		
Yucca schidigera				

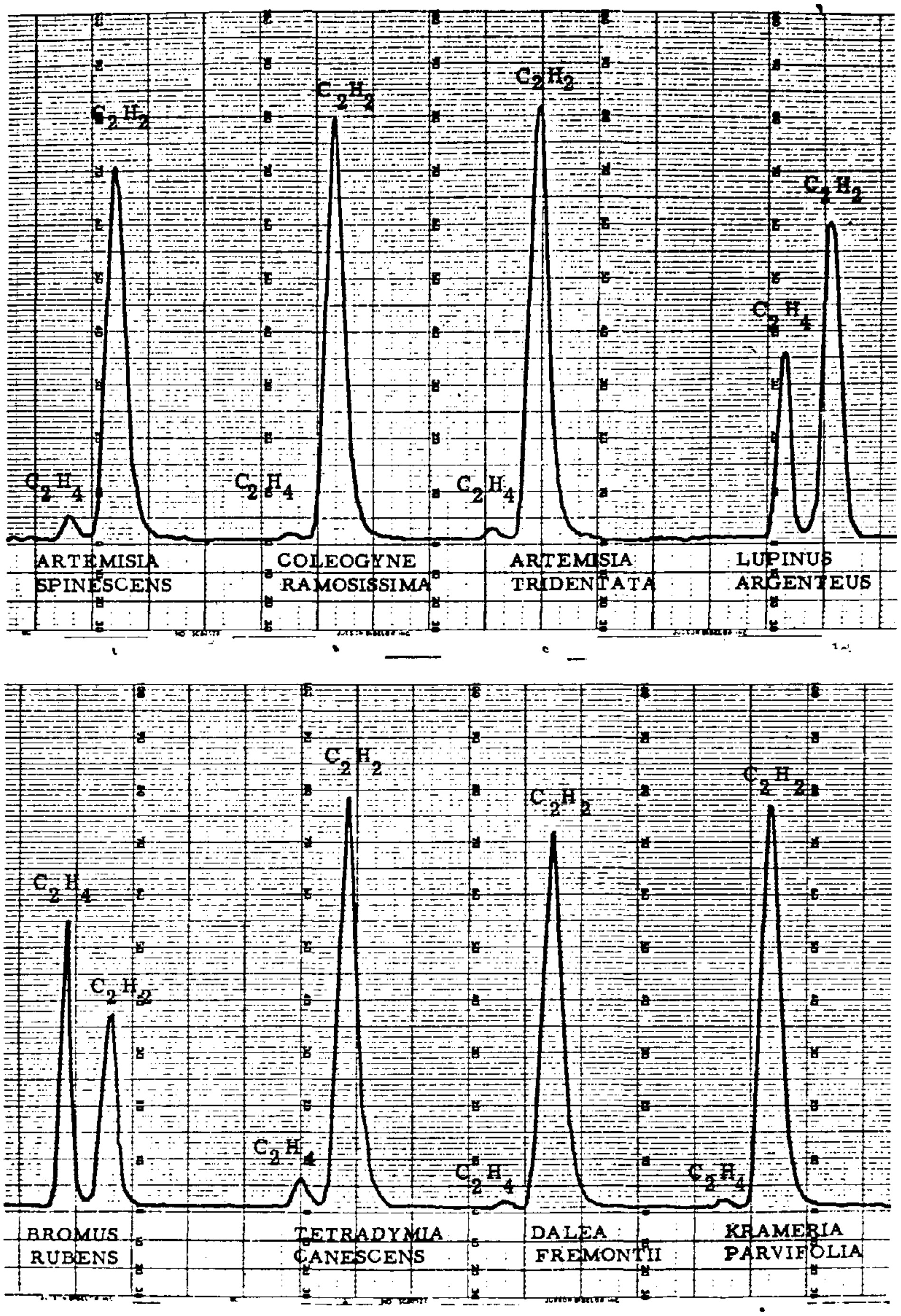


Figure 1. Gas chromatogram tracings of ethylene (C_2H_4) production from acetylene (C_2H_2) in root-soil samples for some different plant species with a common incubation time.

we presume that symbiotic microbial endophytes are primarily involved because of the sensitivity of the reaction to temperature and moisture and its dependence upon the presence of plant roots. Went and Stark (1968) reported that "typical endotrophic mycorrhiza was observed microscopically in the roots of Franseria dumosa, Peucephyllum schottii, and Hymenoclea salsola. All other desert plants both annuals and shrubs, had many hyphae in their rhizosphere and surrounding soil. The dark colored hyphae could often be seen penetrating through the root epidermis." Farnsworth and Hammond (1968) observed nodules on the roots of Artemisia ludoviciana and found that the endophyte isolated from the nodules was bacterial, and presumably functioned in the assimilation of atmospheric nitrogen. The presence of these nodules seemed to be correlated very closely with the supply of early spring moisture and cool soil temperature. Nodules could not be found after soil had dried out near the end of June.

The gas chromatogram tracings in Figure 1 show some examples of the relative activity of the acetylene reduction - ethylene production reaction by root-soil samples with common incubation time. B. rubens and L. argenteus were the most reactive samples detected by our qualitative survey method. B. rubens is an introduced grass species (Beatley, 1966) of ecological significance because it grows primarily within the sheltered canopies of shrubs where nitrogen fixation may be of greatest advantage to native vegetation.

It is well known that leguminous plants may contribute substantially to the nitrogen status of soils; however, symbiotic nitrogen fixation is not restricted to legumes. Diverse non-leguminous angiosperms also fix atmospheric nitrogen by root-nodule symbiosis in association with actinomycetes (Becking, 1970). More than 100 species of 14 genera of 7 families of the nonleguminous angiosperms are reported to have root nodulation (Allen and Allen, 1965; Becking, 1970; Bond, 1963; and Stewart, 1967). Should further investigations on species suggested as possible by our surveys show conclusive presence of root-nodule symbiosis, the following families, genera, and species of non-leguminous plants could be added to those already identified as having root-nodule symbiosis:

Compositae: Tetradymia canescens, Hymenoclea salsola, Artemisia spinescens, Artemisia tridentata. Farnsworth and Hammond (1968) have identified Artemisia ludoviciana.

Rosaceae: Coleogyne ramosissima. The genera Cercocarpus, Dryas and Purshia have been identified in this family.

Gramineae: Bromus rubens.

Krameriaceae: Krameria parvifolia.

Three of the other species which tested positive to the acetylene reduction reaction are Leguminosae: L. argenteus, Dalea fremontii, and A. lentiginosus.

The nitrogen fixation capabilities of lichens is of ecological importance because of their widespread occurrence in desert soils. At our study sites the lichens are most active during the cool, moist winter and early spring months. These associations are probably the most representative of the free-living forms of nitrogen-fixing systems in desert soils. Fuller et al. (1960) identified many genera of algae obtained from desert soils as blue-green algae, many of which are autotrophic both with respect to nitrogen as well as carbon. Their ability to fix atmospheric nitrogen resulted in algae and lichen crusts being four to five times as high in nitrogen as the soil below. This nitrogen was shown to be available to plants. Mayland et al. (1966) found that semi-arid desert algae crusts fixed nitrogen rates of 0.18 and 0.11 kg of nitrogen per hectare of crust surface per day under continuous wet and wet-dry cycling conditions, respectively.

At study areas in the Nevada Test Site we have found the above ground biomass of perennial plants to vary from around 1500 to 5000 kg per hectare and the new annual photosynthetic production on these shrubs to vary from around 200 to 800 kg per hectare. Since the primary production markedly depends upon the seasonal supply of soil moisture, it varies widely from year to year for both annual plants and perennial plants. We have observed the standing crop of winter annuals to range from 50 to 300 kg per hectare at our study sites. Beatley (1969) has reported biomass values for winter annual plants ranging from 0 to 616 kg per hectare on undisturbed soils.

The total nitrogen content of desert soils generally is low. In bare areas we have found the total nitrogen level in soil to vary from less than 0.01 to 0.08 per cent. Under shrub clumps the range is from less than 0.01 to 0.15 per cent and in rare instances we have detected levels up to 0.25 per cent in zones of high organic matter deposition and nitrogen accumulation. The NO_3-nitrogen levels in soil are very low, ranging from 2 to 80 ppm. Fixed forms of nitrogen on the soil colloids range within a factor of 10 higher than the levels of NO_3-nitrogen. The highest levels of nitrogen are not always associated with the higher concentrations of organic matter usually found in the upper horizons of the soil profile. In many soil profiles we have found the nitrogen to be quite uniformly distributed, and zones of accumulation sometimes appear in the B and C horizons especially under shrub clumps. This indicates that leaching of nitrogen into the soil profile is of ecological significance in desert soils.

From our investigations of nitrogen in desert soils and vegetation, we can make the following suppositions: (1) the standing crop contains about 2 per cent nitrogen, (2) about 2 per cent of the nitrogen in soil organic matter could be delivered to the vegetation per year, and (3) about 25 per cent of the total nitrogen in the standing crop is needed for new annual growth. In an Artemisia community in the Great Basin-type desert area, about 240 kg of nitrogen per hectare was in the standing crop with an estimated 60 kg of nitrogen per hectare needed annually. The soil organic matter contained approximately 5,000 kg of nitrogen per hectare, and this could deliver around 100 kg of nitrogen annually for plant growth. This represents one of the more fertile systems in the desert ecosystem and probably reflects the nitrogen fixation reactions seen in the Artemisia species. A less fertile system is represented by a Larrea-Franseria community in the Mojave Desert-type area in which the soil organic matter contained approximately 1050 kg of nitrogen per hectare. The standing crop contained about 45 kg of nitrogen per hectare and of this about 10 kg is needed annually for new plant growth. Since the soil organic matter could supply as much as about 21 kg of nitrogen per hectare, nitrogen would not be deficient nor would atmospheric nitrogen need be fixed to maintain balance on a short-time basis. The input of nitrogen to soil from rainfall and from symbiotic and free-living microbial endophytes, coupled with the sparsity of natural vegetation and relatively high retention of nitrogen in the desert ecosystem, all lead to an explanation for the apparent lack of nitrogen deficiency in desert vegetation around well established shrub clumps. The implication is that soil moisture rather than nitrogen is the most important factor limiting primary productivity in this desert.

Summary

Some seasonal surveys were made to see if nitrogen fixation reactions could be detected in the root zone of the desert vegetation by the acetylene reduction method. Corroborative field studies also were made to determine the response of desert vegetation to nitrogen fertilization with and without supplementary moisture (see page 349).

Root-soil samples from several different plant species showed positive reactions which are presumed to primarily involve symbiotic microbial endophytes because of the sensitivity of the reaction to temperature and moisture and its dependence upon the presence of plant roots. The following species of nonleguminous plants gave positive reactions: *Artemisia spinescens*, *Artemisia tridentata*, *Hymenoclea salsola*, and *Tetradymia canescens* of the Compositae family; *Coleogyne ramosissima* of the Rosaceae family, *Bromus rubens* of the Gramineae family; and *Krameria parvifolia* of the Krameriaceae family. Three members of the Leguminosae family tested positive: *Lupinus argenteus*, *Dalea fremontii*, and *Astragalus lentiginosus*. Lichens which were not identified also tested positive.

Future studies are needed not only to identify the endophyte involved with each species of higher plants which gave a positive reaction to the acetylene reduction test, but also to develop quantitative information concerning the relative importance of each possible association. Further studies are even needed to show effects of ionizing radiation on this component of the ecosystem.

The data serve to show that problems of biological availability of nitrogen have been solved in nature for even very harsh environments.

SALT TOLERANCE OF SOME DESERT SHRUB SPECIES

Soil salinity is one of the more prominent edaphic factors which governs the distribution of plant species in desert ecosystems. Its limiting effect may result from the physiological intolerance of certain species to high levels of salt or from the failure of seeds to germinate and seedlings to survive high salt concentrations in soil (Chatterton and McKell, 1969; Gates et al., 1956; Strogonov, 1964; Ungar, 1962, 1966; Ungar et al., 1969).

A series of glasshouse pot tests were run to evaluate the relative tolerance of several different shrub species to increasing levels of salt in soil. These tests, admittedly subjective, were conducted with 1 to 3 month-old seedlings or rooted cuttings which were transplanted to soils with increasing levels of soluble salts. The period of growth observation was 9 months. Different levels of soil salinity were obtained by blending together varying amounts of a non-saline soil collected from Frenchman Flat and a highly saline Panoche soil collected near Bakersfield, California. Both soils were of similar texture and clay content. The varied levels of soil salinity tested and the relative tolerance of shrub species to these salinity levels are listed in Table 1.

Under the conditions of these tests, the *Atriplex canescens* and *Atriplex hymenelytra* species were the most salt tolerant. The *Franseria dumosa*, *Larrea divaricata*, and *Yucca schidigera* species tolerated moderate levels of soluble salts and they were slightly less sensitive than *Artemisia tridentata* or

Table 1. Relative tolerance of desert shrub species to varied levels of soil salinity derived from different blends of Frenchman Flat and Panoche soils.

Plant species	Blends of soil (Frenchman Flat and Panoche)					
	10FF/0P	8FF/2P	6FF/4P	4FF/6P	2FF/8P	0FF/10P
	mmhos/cm at 25°C					
	0.20	6.92	12.47	17.81	21.68	25.82
	Tolerance evaluation					
A. tridentata	1	3	4	5	5	5
A. spinescens	1	3	4	5	5	5
A. canescens	1	2	3	3	4	5
A. hymenelytra	1	2	3	3	4	5
C. ramosissima	1	5	5	5	5	5
D. fremontii	1	5	5	5	5	5
E. viridis	1	5	5	5	5	5
F. dumosa	1	2	4	5	5	5
G. spinosa	1	5	5	5	5	5
L. divaricata	1	2	4	5	5	5
L. andersonii	1	5	5	5	5	5
Y. schidigera	1	2	3	4	5	5

Salt-tolerance evaluation scale for 9-month growth period:

1 — Normal healthy growth and color.
2 — Visible inhibition of growth without color change.
3 — Marked growth reduction and color change.
4 — Serious damage but still alive after 9 months.
5 — Dead within first 3 months of test.

Artemisia spinescens. The species most sensitive to salts were *Coleogyne ramosissima*, *Dalea fremontii*, *Ephedra viridis*, *Grayia spinosa*, and *Lycium andersonii*. An example of plant growth conditions after 90 days on treatment is shown for *A. canescens* in Figure 1.

Figure 1. Response of *Atriplex canescens* grown 90 days on soil with varied levels of soluble salts. The numbers on the pots are the specific conductance (mmhos/cm at 25°C).

The mineral contents were determined for a set of samples from two representative species, *A. canescens* (Table 2) and *L. divaricata* (Table 3), harvested 90 days after treatment. At this stage of growth only the *L. divaricata* growing at the highest salt level appeared to be dead. Some interesting crossover patterns occurred among major nutrient elements in *A. canescens*. The sodium and phosphorus levels in leaf tissue increased as the soil salinity was increased while the potassium, calcium, and magnesium levels decreased. A similar increase in sodium and phosphorus occurred in stem tissue but only the potassium levels were reduced as soil salinity increased. In root tissue of *A. canescens*, the sodium levels increased while the phosphorus, potassium, calcium, and magnesium levels were decreased. The increased soil salinity levels also caused a reduction of the zinc and manganese levels in leaf tissue and of the manganese levels in root tissue of *A. canescens*.

In *L. divaricata* plants the sodium levels were increased in leaf, stem, and root tissues with an accompanying decrease in the potassium levels of these tissues. There was, however, no significant change in the phosphorus, potassium, calcium, and magnesium levels in leaf, stem, and root tissues of *L. divaricata* with increased levels of soil salinity as was the case for *A. canescens*. The zinc and manganese levels did, however, follow a pattern of reduction with increased salinity similar to that which occurred in *A. canescens*.

The tendency for increased content of sodium in plant parts seemed to be associated with increased anion contents, namely phosphorus and boron. Similar increases could be expected for chlorine, sulfur, and nitrogen which were not measured.

Table 2. Mineral contents in *Atriplex canescens* plants grown 90 days on soil with varied levels of soluble salts.

Soil blend and EC (mmhos/cm at 25° C)	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Al	Sr
	% of dry weight					ppm of dry weight						
				Leaf tissue								
Frenchman Flat (0.20)	0.37	0.24	20.8	5.01	1.16	232	11	605	183	311	1595	178
8FF/2P (6.92)	0.42	2.71	16.2	5.61	1.14	250	15	448	104	354	921	188
6FF/4P (12.47)	0.40	4.28	16.0	4.89	1.19	250	16	302	54	416	896	177
4FF/6P (17.81)	0.25	6.43	13.9	4.73	0.61	211	11	211	32	234	287	149
2FF/8P (21.68)	0.70	11.19	12.2	2.83	0.68	178	16	355	50	268	408	128
Panoche (25.82)	0.81	17.33	10.8	3.41	0.87	155	20	714	75	680	1341	113
				Stem tissue								
Frenchman Flat (0.20)	0.18	0.10	8.1	1.83	0.54	72	8	336	109	55	593	117
8FF/2) (6.92)	0.10	0.27	7.7	1.45	0.34	79	7	272	96	54	419	114
6FF/4P (12.47)	0.15	0.80	6.8	1.32	0.50	104	12	268	59	58	347	109
4FF/6P (17.81)	0.13	2.11	6.1	2.15	0.45	75	8	263	35	41	407	141
2FF/8P (21.68)	0.26	2.42	5.9	1.47	0.46	115	10	337	61	61	756	101
Panoche (25.82)	0.36	2.86	5.6	2.75	0.53	84	16	634	94	94	931	152
				Root tissue								
Frenchman Flat (0.20)	1.54	0.61	6.7	0.95	1.05	119	15	1360	474	67	2888	54
8FF/2P (6.92)	1.00	1.53	6.6	0.80	1.03	119	12	1218	301	63	2449	65
6FF/4P (12.47)	1.07	2.26	6.1	0.65	0.88	151	17	1313	275	49	2470	58
4FF/6P (17.81)	0.88	2.56	4.9	0.56	0.90	147	16	1256	189	63	2199	62
2FF/8P (21.68)	0.22	2.72	2.5	0.64	0.48	48	8	889	84	59	1131	59
Panoche (25.82)	0.90	3.09	1.6	0.59	0.52	112	22	1090	165	129	2314	59

Table 3. Mineral contents in Larrea divaricata plants grown 90 days on soil with varied levels of soluble salts.

Soil blend and EC (mmhos/cm at 25°C)	P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Al	Sr
	% of dry weight					ppm of dry weight						
Leaf tissue												
Frenchman Flat (0.20)	0.57	0.10	6.7	4.90	0.71	250	14	921	169	607	1221	217
8FF/2P (6.92)	0.40	1.81	6.1	4.86	0.69	370	13	714	135	485	1413	215
6FF/4P (12.47)	0.45	2.65	5.0	4.81	0.60	111	17	800	73	497	1081	197
4FF/6P (17.81)	0.79	3.88	6.0	4.40	0.92	153	19	651	58	610	1137	192
2FF/8P (21.68)	0.56	6.24	6.9	3.42	0.64	48	27	527	61	720	1679	213
Panoche (25.82)	1.34	7.68	4.6	4.33	0.84	86	42	1193	57	1414	2429	254
Stem tissue												
Frenchman Flat (0.20)	0.31	0.10	5.6	3.42	0.34	52	42	372	62	102	655	124
8FF/2P (6.92)	0.23	0.63	5.6	3.31	0.41	55	44	343	49	135	795	166
6FF/4P (12.47)	0.30	1.68	2.3	3.17	0.38	59	46	488	36	240	1321	161
4FF/6P (17.81)	0.36	2.68	2.3	3.82	0.33	47	34	384	26	288	458	126
2FF/8P (21.68)	0.43	5.28	3.3	3.80	0.42	51	32	360	29	559	421	141
Panoche (25.82)	0.59	6.25	2.2	3.63	0.45	46	33	408	24	669	759	135
Root tissue												
Frenchman Flat (0.20)	0.89	0.36	2.3	2.57	0.42	112	29	1093	189	249	2313	146
8FF/2P (6.92)	1.04	0.78	2.3	3.14	0.68	185	22	1054	188	296	3349	138
6FF/4P (12.47)	1.57	1.38	4.5	2.54	0.63	146	24	1235	172	298	3656	129
4FF/6P (17.81)	1.21	1.48	1.6	2.25	0.59	133	33	1050	121	214	2385	132
2FF/8P (21.68)	1.32	2.16	1.0	2.08	0.72	125	26	1325	145	341	2358	143
Panoche (25.82)	1.11	2.44	1.1	1.89	0.59	131	16	946	65	374	1576	122

Summary

Several different perennial plant species were tested for salt tolerance by growing seedlings and rooted cuttings for 9 months on soils with increasing levels of salinity. Only *Atriplex canescens* and *Atriplex hymenelytra* survived very high salinity conditions and these plants did not grow well at salt concentrations producing conductivity levels above 12.45 mmhos/cm at 25° C. Species that seemed to tolerate moderate levels of salinity included *Franseria dumosa*, *Larrea divaricata*, and *Yucca schidigera*; these shrubs did not grow well at EC25° C levels above 6.92 mmhos/cm. The *Artemisia tridentata* and *Artemisia spinescens* species were salt sensitive but not nearly so much as the highly sensitive species *Coleogyne ramosissima*, *Dalea fremontii*, *Ephedra viridis*, *Grayia spinosa*, and *Lycium andersonii*.

MINERAL ELEMENT CONTENT OF SOME NORTHERN MOJAVE DESERT PLANTS

Among the objectives of our research program are studies of the distribution and interrelationship of mineral elements in desert vegetation. To assist in these studies, advantage was taken of an emission spectrometric analytical system which requires little sample preparation, is simple to operate, and is capable of determining some 20 elements commonly observed in plant tissue. Multielement analysis of plant samples offers several distinct advantages over single element analysis, one of which permits an evaluation of how those elements known to be essential for plant growth interact with one another and with non-essential elements also found in plant tissue.

Materials and Methods

The analytical system in use was assembled by George V. Alexander. Essentially this system involves an Applied Research Laboratories 1.5 m, direct reading emission spectrometer modified and interfaced with an IBM 026 key punch using a Dymec 2013D Data Acquisition System to permit the signal intensity to be transferred to punch cards for final processing. The computer programs used to carry out the calculations needed to calibrate the system for analysis and also to convert signal intensity levels to concentration values are run on the UCLA IBM 360/91 computer.

Plant samples were collected from study areas at the Nevada Test Site. Oven dried samples were processed for spectrometric analysis by methods developed by Alexander and Romney. Briefly, this involves grinding plant tissue in a plastic container using the No. 5000 mixer/mill manufactured by Spex Industries, Inc. This mixer/mill is a high speed impact shaker in which a lucite plastic pellet pulverizes plant material inside a polystyrene vial. The sample is free from contact with metal surfaces during the grinding process. Weighed amounts of dry, powdered tissue varying from 5 to 10 mg are placed in crater electrodes for analysis. A very carefully designed electrode system serves to reproducibly volatilize and excite the sample and thus eliminate the need for an internal standard. One of the advanced features of this technique is the development of a method for determining the background values of the carbon arc in order to arrive at true line intensity.

In addition to converting signal intensity levels to concentration values, the computer program also calls for some statistical evaluation of the data. Included are calculations of the mean and standard deviation, the median and the Pearsonian measure of the amount of skewness present in the frequency distribution of a sample population. This latter measure of skewness is calculated by the method described by Croxton (1959, p. 93-95). Figure 1 is a computer-plotted histogram illustrating the frequency distribution of the calcium content of Grayia spinosa leaves collected from the Nevada Test Site.

Results and Discussion

Considerable data on the mineral element content of plant samples are presented elsewhere in this report. Tables 1 to 5 include data on the mineral contents found in leaves and stems of five prominent shrub species sampled from the Nevada Test Site. Some interesting differences occur among these species. For example, the leaves of Franseria dumosa tend to accumulate more phosphorus, boron, aluminum, and lithium than do leaves of the other species.

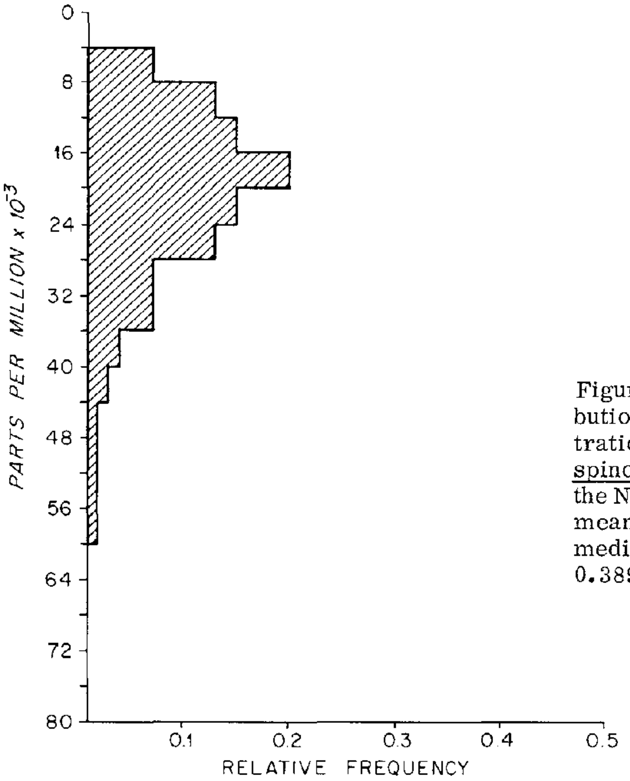


Figure 1. Frequency distribution of the calcium concentration in samples of Grayia spinosa leaves collected from the Nevada Test Site. N = 225; mean = 2.092%; S.D. = 0.961%; median = 1.970%; Skewness = 0.389.

Grayia spinosa leaves accumulate very high levels of potassium. The leaves of Larrea divaricata generally contain lower levels of sodium, potassium, and calcium than are found in leaves of the other shrub species. The two Lycium species show marked differences in some mineral element contents. Lycium andersonii leaves are notably low in sodium and high in calcium while Lycium pallidum leaves are high in sodium and lower in calcium contents.

Table 6 contains data on the mineral contents in mixed desert grasses and annual plants. The compositing of data was done by computer calculations to reflect the mineral element composition in the forage diet of grazing animals. Species included in the mixed grasses are Bromus rubens, Festuca octoflora, Hilaria jamesii, Sitanion hystrix, and Stipa speciosa. Included in the annual species are Encelia virginensis, Stephanomeria pauciflora, Phacelia fremontii, Phacelia vallis-mortae, Oenothera primiveris, Eriogonum inflatum and Ceanothus greggii.

The distribution of mineral elements in leaves of F. dumosa and L. andersonii collected from different areas of the Nevada Test Site is shown in Table 7. Some differences in element content occur among samples collected from different areas, but a more interesting feature of these data is the lack of marked changes in the mineral element composition of plants grown in different areas. Part of this is due to the fact that none of the elements measured are deficient in the soils of these areas with respect to meeting the needs of existing vegetation.

Table 1. Mineral element composition of *Franseria dumosa* shrubs sampled from the Nevada Test Site.

	Concentration of element in oven-dry tissue							
	Franseria dumosa leaves				*Franseria dumosa* stems			
Element	N.	Mean	S.D.	Sk.	N.	Mean	S.D.	Sk.
P, %	264	0.367	0.111	0.267	318	0.154	0.069	0.593
Na, %	248	0.097	0.071	0.456	314	0.133	0.136	0.962
K, %	270	3.590	1.076	-0.116	323	2.905	0.928	-0.248
Ca, %	266	3.131	0.831	0.237	317	1.601	0.421	0.346
Mg, %	263	0.545	0.120	0.229	323	0.392	0.105	0.065
Si, %	270	0.348	0.153	0.487	313	0.106	0.081	0.822
Zn, ppm	174	33.7	17.0	-0.518	245	23.4	11.7	-0.251
Cu, ppm	268	11.6	7.6	0.886	309	10.8	7.8	0.930
Fe, ppm	269	366.4	141.6	0.295	309	140.7	88.3	0.800
Mn, ppm	258	47.2	21.3	0.743	309	29.7	16.3	0.567
B, ppm	262	178.6	65.1	0.476	316	46.0	19.5	0.733
Al, ppm	269	681.5	317.9	0.346	320	223.7	155.3	0.672
Mo, ppm	251	2.3	0.8	0.823	170	1.5	0.8	1.382
Sn, ppm	130	3.1	1.6	0.483	137	3.0	1.8	0.609
Cr, ppm	109	4.0	4.2	1.175	83	11.7	8.4	0.992
Sr, ppm	254	162.1	99.8	0.566	308	126.7	57.1	0.129
Ba, ppm	264	19.7	10.8	0.528	317	24.7	10.6	0.237
Li, ppm	30	106.0	16.0	1.487	-	-	-	-
Ag, ppm	123	1.4	0.9	0.681	-	-	-	-
Pb, ppm	63	4.6	3.4	0.671	61	6.7	6.5	0.948
	N = 270				N = 324			

N = number of observations with a value greater than the lower detection limit and within 3 S.D. of the mean; S.D. = standard deviation; Sk. = skewness.

Table 2. Mineral element composition of *Grayia spinosa* shrubs sampled from the Nevada Test Site.

Concentration of element in oven-dry tissue

	Grayia spinosa leaves				*Grayia spinosa* stems			
Element	N.	Mean	S.D.	Sk.	N.	Mean	S.D.	Sk.
P, %	225	0.186	0.094	0.466	275	0.124	0.052	0.179
Na, %	206	0.143	0.184	1.156	252	0.027	0.033	1.095
K, %	231	8.920	2.510	0.311	273	2.783	1.257	-0.345
Ca, %	225	2.092	0.961	0.389	269	1.366	0.544	0.426
Mg, %	229	1.073	0.247	0.678	280	0.341	0.113	0.205
Si, %	232	0.128	0.085	0.919	250	0.044	0.025	0.653
Zn, ppm	155	27.6	14.8	-0.254	212	19.6	10.2	0.197
Cu, ppm	221	7.9	4.0	0.649	264	7.8	4.4	0.651
Fe, ppm	225	171.0	67.3	0.571	265	72.4	37.6	0.314
Mn, ppm	228	106.4	39.5	0.378	271	29.8	15.7	0.610
B, ppm	232	50.4	18.1	0.395	269	24.2	9.3	-0.256
Al, ppm	224	226.9	128.5	0.277	263	90.7	65.0	0.734
Mo, ppm	227	3.4	1.4	0.475	67	1.5	0.5	0.844
Sn, ppm	166	5.6	3.1	0.242	112	2.8	2.1	1.314
Cr, ppm	62	9.8	12.4	1.871	44	10.3	7.0	0.643
Sr, ppm	218	76.5	39.1	0.340	267	85.9	32.9	-0.189
Ba, ppm	223	12.4	5.5	0.820	273	14.2	6.2	0.527
Li, ppm	40	6.8	2.7	1.325	-	-	-	-
Ag, ppm	120	1.4	1.1	0.784	157	0.7	0.3	0.370
Pb, ppm	99	13.5	8.8	0.881	27	6.6	5.9	1.216
	N = 234				N = 280			

N = number of observations with a value greater than the lower detection limit and within 3 S.D. of the mean; S.D. = standard deviation; Sk. = skewness.

Table 3. Mineral element composition of *Larrea divaricata* shrubs sampled from the Nevada Test Site.

Concentration of element in oven-dry tissue

	Larrea divaricata leaves				*Larrea divaricata* stems			
Element	N.	Mean	S.D.	Sk.	N.	Mean	S.D.	Sk.
P, %	272	0.215	0.082	0.018	246	0.168	0.066	0.090
Na, %	257	0.062	0.054	0.910	246	0.062	0.055	0.811
K, %	280	1.904	0.514	-0.158	266	1.607	0.493	-0.275
Ca, %	279	1.517	0.416	-0.246	261	1.209	0.358	0.144
Mg, %	280	0.242	0.074	0.400	264	0.248	0.078	0.348
Si, %	274	0.385	0.225	0.888	262	0.467	0.281	0.619
Zn, ppm	209	22.1	10.7	-0.101	198	18.8	8.7	-0.050
Cu, ppm	262	8.8	7.4	1.115	255	9.4	7.0	1.194
Fe, ppm	275	420.7	207.7	1.044	263	515.0	259.2	0.373
Mn, ppm	275	47.9	23.1	0.889	262	35.4	18.6	0.907
B, ppm	280	105.8	47.2	0.872	246	39.4	10.8	0.125
Al, ppm	273	630.4	364.7	0.958	262	717.7	387.3	0.455
Mo, ppm	209	1.7	0.7	0.914	114	1.7	0.7	0.482
Sn, ppm	70	2.1	1.1	1.381	86	2.8	1.5	1.031
Cr, ppm	106	8.7	11.8	1.596	99	3.5	2.9	1.243
Sr, ppm	272	105.9	54.9	0.247	256	115.9	55.5	0.077
Ba, ppm	269	17.6	8.9	0.996	256	24.9	12.5	0.778
Li, ppm	3	5.1	1.4	-0.478	2	4.4	1.9	0.000
Ag, ppm	106	0.9	0.7	0.718	100	1.1	0.8	1.320
Pb, ppm	63	6.8	5.2	-0.086	71	8.0	5.7	0.645
	N = 282				N = 266			

N = number of observations with a value greater than the lower detection limit and within 3 S.D. of the mean; S.D. = standard deviation; Sk. = skewness.

Table 4. Mineral element composition of *Lycium andersonii* shrubs sampled from the Nevada Test Site.

Concentration of element in oven dry tissue

	Lycium andersonii leaves				*Lycium andersonii* stems			
Element	N.	Mean	S.D.	Sk.	N.	Mean	S.D.	Sk.
P, %	239	0.131	0.066	-0.054	302	0.129	0.047	-0.041
Na, %	259	0.053	0.064	1.291	273	0.030	0.038	1.209
K, %	280	4.352	1.357	0.246	302	1.488	0.684	0.084
Ca, %	280	6.916	1.966	0.423	295	2.00	0.627	0.098
Mg, %	278	1.050	0.302	0.167	302	0.259	0.099	0.368
Si, %	263	0.125	0.068	0.860	257	0.055	0.034	0.452
Zn, ppm	151	53.5	22.8	-0.174	232	24.7	12.4	-0.304
Cu, ppm	264	8.2	5.8	1.191	296	11.7	7.8	0.413
Fe, ppm	264	175.0	65.2	0.801	284	95.4	60.5	0.739
Mn, ppm	273	39.8	20.9	0.606	302	13.6	7.7	0.827
B, ppm	278	83.4	23.7	0.329	294	24.3	12.6	0.594
Al, ppm	263	265.4	126.6	0.793	286	143.3	114.8	0.816
Mo, ppm	278	6.5	2.9	0.272	158	1.6	0.6	0.917
Sn, ppm	81	3.9	2.6	0.193	141	3.9	3.2	0.994
Cr, ppm	125	9.7	11.2	1.562	79	10.5	9.7	1.150
Sr, ppm	198	291.9	214.5	1.074	293	151.1	71.9	-0.059
Ba, ppm	274	34.7	20.1	1.049	297	14.3	6.2	0.559
Li, ppm	222	4.4	3.2	0.566	6	17.7	15.1	0.779
Ag, ppm	106	2.6	1.3	-0.334	155	0.8	0.4	0.492
Pb, ppm	39	12.1	8.8	-0.159	64	9.1	6.4	0.428
	N = 281				N = 306			

N = number of observations with a value greater than the lower detection limit and within 3 S.D. of the mean; S.D. = standard deviation; Sk. = skewness.

Table 5. Mineral element composition of *Lycium pallidum* shrubs sampled from the Nevada Test Site.

Concentration of element in oven-dry tissue

	Lycium pallidum leaves				*Lycium pallidum* stems			
Element	N.	Mean	S.D.	Sk.	N	Mean	S.D.	Sk.
P, %	34	0.181	0.086	0.248	32	0.137	0.054	0.327
Na, %	36	0.955	0.782	0.410	31	0.049	0.047	-0.113
K, %	37	3.774	1.424	0.198	32	2.097	1.082	0.226
Ca, %	37	3.075	1.452	-0.004	32	1.731	0.808	0.581
Mg, %	35	1.251	0.271	0.300	29	0.313	0.075	0.421
Si, %	36	0.108	0.046	-0.513	29	0.045	0.025	0.487
Zn, ppm	24	31.6	13.0	0.130	22	24.0	10.7	-0.183
Cu, ppm	37	7.5	6.4	1.274	29	6.6	4.6	1.061
Fe, ppm	37	188.5	72.9	0.516	32	76.3	43.8	-0.065
Mn, ppm	36	101.6	46.3	-0.215	32	13.2	8.3	1.019
B, ppm	36	63.9	12.7	0.340	32	22.9	9.9	0.335
Al, ppm	37	231.6	118.5	-0.136	32	96.8	68.6	0.192
Mo, ppm	37	7.7	2.2	-0.158	23	2.7	1.5	0.961
Sn, ppm	22	4.2	2.2	0.002	15	2.3	1.1	-1.052
Cr, ppm	11	5.0	3.4	-0.047	4	2.1	0.8	0.000
Sr, ppm	36	268.5	441.7	1.203	32	237.2	390.5	1.248
Ba, ppm	35	17.5	10.9	0.777	30	11.3	4.7	0.646
Li, ppm	31	34.7	18.0	0.036	1	4.6	0.0	0.000
Ag, ppm	8	1.2	1.0	0.465	9	0.9	0.8	1.098
Pb, ppm	6	5.4	6.1	1.689	-	-	-	-
	N = 37				N = 32			

N = number of observations with a value greater than the lower detection limit and within 3 S.D. of the mean; S.D. = standard deviation; Sk. = skewness.

Table 6. Mineral element composition of mixed desert grasses and mixed desert annuals sampled from the Nevada Test Site.

	Concentration of element in oven-dry tissue							
	Mixed desert grasses				Mixed desert annuals			
Element	N.	Mean	S.D.	Sk.	N.	Mean	S.D.	Sk.
P, %	130	0.146	0.064	-0.033	50	0.312	0.192	0.885
Na, %	113	0.014	0.012	0.841	50	0.100	0.153	1.103
K, %	133	1.662	0.797	-0.379	52	3.103	1.571	0.429
Ca, %	136	0.389	0.256	0.181	52	1.530	0.799	-0.149
Mg, %	136	0.179	0.069	0.022	52	0.472	0.314	0.021
Si, %	139	1.421	0.561	-0.513	50	0.436	0.437	1.526
Zn, ppm	94	16.3	7.2	0.374	25	159.1	265.0	1.546
Cu, ppm	125	9.9	9.9	0.806	50	11.2	7.6	1.013
Fe, ppm	135	160.2	117.5	0.321	51	440.7	398.9	1.035
Mn, ppm	139	96.6	56.6	0.665	50	64.9	43.6	0.427
B, ppm	136	35.4	24.2	0.619	50	64.1	28.4	-0.253
Al, ppm	137	158.1	155.4	0.892	52	784.5	832.5	1.045
Mo, ppm	102	2.1	1.0	0.098	42	3.3	1.2	-0.047
Sn, ppm	35	2.9	1.5	0.763	42	4.1	2.0	-0.363
Cr, ppm	-	-	-	-	36	3.9	2.4	0.598
Sr, ppm	122	62.0	76.6	0.413	52	488.3	501.4	1.880
Ba, ppm	128	20.9	12.9	0.318	52	78.5	47.6	-0.829
Li, ppm	2	5.3	0.0	0.000	2	3.4	0.0	0.000
Ag, ppm	48	0.5	0.4	1.053	24	1.7	1.6	0.665
Pb, ppm	36	5.9	5.2	1.693	10	3.9	1.1	2.062
	N = 139				N = 52			

N = number of observations with a value greater than the lower detection limit and within 3 S.D. of the mean; S.D. = standard deviation; Sk. = skewness.

Table 7. Comparative mineral contents in leaf tissue of desert shrubs sampled from different areas of the Nevada Test Site.

Sample location	N[b]	P	Na	K	Ca	Mg	Si	Zn	Cu	Fe	Mn	B	Al	Mo	Sn	Cr	Sr	Ba	Li
	% of oven-dry tissue							ppm of oven-dry tissue											
						Franseria dumosa													
Jackass Flats (8)[a]	2.82	.368	.076	4.28	4.22	0.489	.364	49	5.2	401	77	106	848	1.6	1.3	1.4	283	20	
Rock Valley (12)	2.23	.269	.071	4.52	3.58	0.669	.266	31	5.1	317	42	202	526	3.2	3.2	2.3	117	11	
Mercury Plots (10)	2.65	.162	.073	3.89	2.83	0.742	.362	33	5.0	235	45	212	648	5.4	2.7	1.7	122	16	
F. Flat - North (5)	2.21	.291	.114	3.68	2.96	0.768	.383	41	5.3	381	88	165	960	2.8	3.2	1.6	370	19	
F. Flat - West (8)	3.03	.284	.051	4.26	3.71	0.552	.255	37	6.4	275	67	139	562	2.9	3.5	1.3	246	15	
						Lycium andersonii													
Jackass Flats (3)*	3.57	.223	.035	3.34	8.39	0.82	.142	58	3.8	176	112	76	253	6.4	1.9	1.6	662	28	24
Rock Valley (26)	3.18	.142	.058	3.88	6.35	1.06	.097	34	8.2	164	57	91	224	9.3	1.5	1.6	236	28	94
Mercury Plots (46)	3.54	.151	.064	4.23	7.16	1.09	.117	45	6.5	193	46	85	280	6.4	3.3	1.1	217	33	56
F. Flat - North (5)	2.67	.142	.029	5.79	7.46	1.37	.166	63	3.5	191	64	99	264	1.3	5.0	8.1	747	42	31
F. Flat - East (5)	3.29	.147	.017	4.63	8.66	1.59	.149	59	2.4	164	61	96	197	9.3	7.4	1.3	667	41	12
F. Flat - West (9)	3.55	.167	.030	4.38	9.22	0.94	.107	63	6.6	117	67	81	132	1.1	5.5	3.7	372	20	11
Yucca Flat (8)	3.45	.193	.027	5.12	5.08	1.22	.155	44	8.7	192	67	72	341	6.2	4.2	1.0	237	56	24
Groom Valley (8)	3.07	.073	.102	3.75	6.76	1.03	.116	52	5.6	187	38	89	345	4.2	3.2	3.8	627	49	168

[a] Number of sample replicates from which mean was derived.

[b] Nitrogen was determined by Kjeldahl method.

F. Flat is Frenchman Flat.

Summary

Advantage was taken of an emission spectrometric analytical system to assist in studies of the distribution and interrelationship of mineral elements in desert vegetation. This system is capable of determining in each sample some 20 elements commonly observed in plants. It permits an evaluation of the interaction among essential and nonessential elements in plant tissue.

Tabulated herein are data on mineral element composition of oven-dry tissue samples for five prominent shrub species and some mixed grasses and annual plants collected from the Nevada Test Site.

STABLE CESIUM ANALYSES BY NEUTRON ACTIVATION OF PLANTS FROM THE NEVADA TEST SITE

Cesium contents of leaves were determined for several species of plants collected from the Nevada Test Site by a neutron-activation analysis technique (Table 1). The concentrations of stable cesium varied from 30 to 372 nanograms per gram dry weight. The cesium values were unrelated to the potassium and sodium contents. The correlation coefficients of Cs × Fe, Cs × Ti, and Cs × Al respectively were +0.833, +0.950, and +0.738. It is not known how much of this high degree of correlation may be related to external contamination but the leaves were carefully sampled.

Table 1. Contents of cesium and other elements in leaves of several plant species collected from the Nevada Test Site.

Sample	Na	K	Ca	Si	Fe	Mn	Al	Ti	Cs
	% of dry weight				ppm of dry weight				Nanograms /gram
L. andersonii from Rock Valley	2.39	3.04	5.86	.09	117	73	183	8	34
L. pallidum from Rock Valley	.96	2.86	3.04	.09	129	99	191	6	30
A. tridentata from Yucca Mtn	.022	2.72	1.36	.14	146	245	188	11	51
A. spinescens from Frenchman Flat	.11	3.25	1.67	.58	540	246	951	94	372
A. canescens from 40-mi Canyon	.97	4.72	1.52	.15	166	170	286	10	67
A. confertifolia from Rock Valley	7.52	10.68	2.05	.11	142	116	164	4	39
G. spinosa from Rock Valley	.48	13.41	1.97	.10	140	185	99	2	41
L. divaricata from Rock Valley	.10	2.07	1.47	.66	449	63	969	39	142
F. dumosa from Rock Valley	.088	4.44	2.87	.24	227	81	381	13	59
K. parvifolia from Rock Valley	.10	2.28	1.17	.19	276	60	332	16	128
C. ramosissima from Yucca Mtn.	.039	1.54	2.87	.19	176	112	279	12	110
E. virginensis from 40-mi Canyon	.074	3.25	2.92	.54	340	182	685	26	65
O. hymenoides from Rock Valley	.027	1.96	0.49	1.31	177	107	179	11	40
E. lanata from Rock Valley	.081	3.04	1.98	.19	259	185	402	18	42

To determine the effect of a cesium application to soil on the ability of plants to accumulate cesium from the soil, an experiment was conducted in which 0, 10, 40, or 100 parts cesium per million parts soil as CsCl salt were carefully mixed with the soil collected from near the study plots at Mercury on the Nevada Test Site. Atriplex canescens cuttings were grown in the soil for 70 days in triplicate. Leaf samples were taken and assayed for stable cesium by neutron activation. The mean coefficient of variation of the triplicate samples was 8.6%. The mean contents in the leaves for the 0, 10, 40, and 100 parts per million application rate were 0.0279, 0.580, 5.15, and 24.0 ppm of dry weight, respectively. Although the uptake was consistent and measurable, it was only about 1/100 to 1/500 of what could be expected for an equivalent potassium application. It is known that cesium is much less available from soil than is potassium (Nishita et al., 1965).

EFFECT OF WASHING ON MINERAL COMPOSITION OF LEAVES OF ATRIPLEX SPECIES GROWN AT DIFFERENT SODIUM LEVELS

Three Atriplex species, A. canescens, A. confertifolia, and A. hymenelytra, growing in soil were watered two or three times a week for 6 weeks. One set of plants received water only while another set received water containing NaCl (approx 200 ml of water containing 40 me per liter NaCl). (The plants were growing in containers of from 400 g to 1200 g of soil). The plants which received the NaCl are assumed to be "high sodium plants" while the ones which did not receive NaCl are assumed to be "low sodium plants."

After 6 weeks (15 Jan. to 25 Feb. 1970) the leaves of the plants were collected, divided into three groups and each group was given a different washing treatment (no wash, slight wash, or extensive wash). The leaves were then oven-dried and prepared for analyses by emission spectography.

Experimental Results

Data are given in Table 1. Only in the case of iron of the essential elements was there a consistent decrease in leaf content with washing. In general aluminum and silicon contents were also decreased by washing. Even though there was large quantities of sodium in leaves of the species, it was not washed from the leaves by the treatments. Even though the sodium is probably compartmented in salt glands it was not available to the washing solution.

These results indicate that extremely serious errors are not likely for failure to wash leaves collected from the field. This is particularly so for newly developed leaves. There are places and times of the year when dust is very prevalent on foliage; we always tried to avoid collecting such plant material.

Table 1. Effect of washing on contents of mineral elements in leaves of Atriplex species grown at different sodium chloride levels.

Species	Type of wash	% of dry weight					ppm of dry weight											
		P	Na	K	Ca	Mg	Zn	Cu	Fe	Mn	B	Al	Si	Co	Ni	Mo	Sr	Ba
							Low-salt plants											
A. canescens	A	1.17	0.14	14.0	1.2	0.46	136	39	165	148	41	121	0.13	1.8	4.3	21.5	5.1	44.0
	B	0.99	0.12	16.9	0.4	0.42	131	44	105	207	39	1	0.02	1.5	4.5	21.0	3.9	22.6
	C	1.13	0.18	11.4	0.7	0.50	79	41	115	189	30	1	0.02	1.8	4.3	17.3	5.1	43.8
A. confertifolia	A	2.15	2.05	11.1	2.1	0.89	172	46	200	264	39	19	0.10	3.3	8.6	4.2	6.6	75.8
	B	2.29	2.21	10.3	2.2	0.92	173	49	132	290	41	13	0.06	3.3	6.9	4.9	6.1	68.8
	C	2.36	2.09	12.1	2.7	0.91	200	51	136	298	41	31	0.09	4.1	7.7	5.5	8.1	78.1
A. hymenelytra	A	2.66	4.08	11.5	1.7	0.78	126	37	86	249	39	12	0.09	1.9	4.5	5.6	8.3	40.2
	B	2.56	3.64	11.1	1.7	0.74	142	36	62	234	39	3	0.07	1.7	3.7	6.1	8.0	29.8
	C	2.77	3.58	12.0	1.7	0.78	126	35	74	250	34	5	0.07	1.6	4.7	5.9	8.1	38.1
							High-salt plants											
A. canescens	A	3.00	1.11	13.4	1.8	1.22	224	52	257	348	53	40	0.14	2.4	6.0	7.4	8.3	65.2
	B	3.04	1.20	14.2	1.6	1.11	238	43	136	320	46	7	0.06	2.2	5.1	5.9	9.8	61.1
	C	3.42	1.50	16.3	1.5	1.24	362	47	155	360	46	2	0.04	1.5	4.3	5.2	10.2	53.9
A. confertifolia	A	2.13	11.0	10.5	1.8	0.68	226	44	147	314	43	27	0.08	2.1	4.0	<0.5	5.9	65.5
	B	2.10	9.8	5.5	1.3	0.64	207	40	113	303	36	1	0.03	3.3	5.8	0.9	7.7	51.3
	C	2.43	10.8	8.7	1.7	0.68	255	50	118	311	36	2	0.04	2.6	4.5	0.8	7.1	63.0
A. hymenelytra	A	1.78	11.4	9.4	1.8	0.73	110	38	110	248	37	20	0.07	1.7	4.7	1.6	7.4	37.5
	B	1.75	11.3	10.9	1.6	0.84	135	29	57	264	40	2	0.05	<.05	2.6	<.05	6.2	39.5
	C	1.72	10.5	10.5	1.4	0.58	142	33	58	209	38	2	0.04	<.05	2.4	<.05	6.7	28.0

A = no wash
B = slight wash
C = extensive wash

CYCLING OF STABLE CESIUM IN A DESERT ECOSYSTEM

Introduction

The cycling in ecosystems of radiocesium, particularly of ^{137}Cs, is of vital importance in that many food chains which extend to man result in concentration of ^{137}Cs which in turn could be dangerous to man if the tolerance level is exceeded. Insufficient information is known about the role of stable cesium in the cycling of ^{137}Cs (Nishita et al., 1960, 1965). The major purposes of this paper are to report the levels of stable cesium in various compartments of a desert ecosystem and to estimate the importance of its role in ^{137}Cs cycling.

Materials and Methods

Stable cesium was assayed by neutron activation analysis. The neutron activation techniques employed in this study were similar to those outlined by Bowen and Gibbons (1963). The solubilization of the samples and the final determination of the induced ^{134}Cs was done using methods outlined by Harley et al. (1970).

Duplicate plant and insect samples were run when sufficient material was available. All soil samples were run at least in triplicate. Triplicate comparator plant samples were run with each set of unknown (set contained 16 samples plus three comparators). All counting was done using a Beckman wide-beta counting system.

Stable potassium in soils was assayed for by counting ^{40}K by gamma-ray spectrometry. Mineral elements in biological samples were assayed with an emission spectrograph (unpublished methods of Alexander and Romney).

The samples of soils, plants, and animals were obtained from the Rock Valley area of the Nevada Test Site in 1969 and 1970. The area is an example of the northern part of the Mojave Desert.

Results and Discussion

The analyses for stable cesium and potassium in various components of the northern Mojave Desert ecosystem are in Table 1. The cesium content of soils varied around 4 micrograms per g of soil but that of the biological materials was mostly less than 100 nanograms per g of dry weight. The relatively high level in certain arthropods was very likely related to the presence of soil in the digestive organs of ground-dwelling species. The average potassium per cesium ratio in soil was 5400. The mean of the ratios for 64 samples of plant leaves was 675,000 with 285,000 for reptiles and 181,000 for mammals. The fact that the ratio was much more narrow for soil than for the biota is probably illustrative of the unavailable nature of soil cesium to plants (Gissel-Nielsen and Andersen, 1967; Hanson, 1967; Nishita et al., 1960, 1968). A fraction of it, however, does enter into biological cycling (Table 2).

The relationship between potassium and cesium in various compartments appears to be irregular (Table 1). There was a strong positive relationship between the amounts of cesium and potassium in soil. This is further emphasized in the distribution of potassium and cesium in the soil profile (Table 3). There was insufficient concentration of ^{137}Cs to contribute to the total amount present (Table 3). In contrast to the strong positive relationship between cesium and potassium in soil, there was a strong negative relationship between

Table 1. Contents of stable cesium and potassium in leaves of various plants and in other compartments of a desert ecosystem (dry weight basis).

Material	No of samples	Cs nanograms/g	K %	K/Cs 1000's ratio	Cs×K r
Larrea divaricata leaves	12	79.7 ± 33.2	2.04 ± 0.74	256	-.402
Franseria dumosa leaves	10	73.7 ± 34.5	4.62 ± 1.06	626	+.548
Lycium andersonii leaves	10	57.4 ± 38.8	4.85 ± 1.41	845	+.368
Krameria parvifolia leaves	4	25.8 ± 14.0	2.96 ± 0.99	1147	-.133
Lycium pallidum leaves	4	54.0 ± 10.8	4.41 ± 0.98	817	-.910
Coleogyne ramosissima leaves	4	74.9 ± 32.1	1.28 ± 0.06	171	-.323
Eurotia lanata leaves	9	103.4 ± 44.2	4.07 ± 2.36	394	-.347
Grayia spinosa leaves	11	50.6 ± 25.8	9.51 ± 2.33	1879	+.180
All leaves	64	68.3 ± 37.3	4.61 ± 2.93	675	-.176
Reptiles	1	40.4	1.15	285	—
Mammals	9	50.9 ± 23.7	0.92 ± 0.13	181	-.784
Insects	8	67.0 ± 31.3	— —	—	—
Other arthropods	3	503.0±234.8	— —	—	—
Soils	25	4158.0±293	2.23 ± 0.49	5.4	-.715

± values are the standard deviations.

Table 2. Estimate of the amounts of stable cesium in a desert ecosystem entering into the biological cycle.

Compartment	Compartment size kg/ha	Cs g/ha	Cs Fraction of total
Soil (60 cm)	9.0×10^6	37,200	1.0
Exchangeable cation (60 cm)	13.5×10^3	1,500	0.04
Plants	3000	0.21	0.56×10^{-5}
Arthropods	1.0	0.00019	0.51×10^{-8}
Reptiles	0.4	0.000016	0.43×10^{-9}
Mammals	0.6	0.000031	0.83×10^{-9}

Table 3. Potassium, cesium, and ^{137}Cs contents in soil profiles from Rock Valley area of the Nevada Test Site.

	A horizons	C horizons
K, mg/g soil	25.68 ± 4.45	18.83 ± 3.30
Cs, μ/g soil	4.35 ± 0.22	3.96 ± 0.03
^{137}Cs, pc/g soil	0.283 ± 0.044	0.055 ± 0.028

cesium and potassium in the mammals. The average correlation coefficient for plants was slightly negative but positive relationships were indicated for some species and negative relationships for others (Table 1). This may indicate the operation of different types of mechanisms in various species. Potassium did not seem to compete with cesium for transport in the mammals. This conclusion is based on the observation that the potassium per cesium ratio is narrower in mammals than in plants. If it were wider than for plants, one could have concluded that the mammal tissues could selectively transport potassium in preference to cesium. The process, however, seemed to be concentration rather than dilution. All mammals studied were herbivores.

To determine the effect of a stable cesium application to soil on the ability of plants to accumulate it from the soil, an experiment was conducted in which 0, 5, 20, or 50 ppm cesium as CsCl was mixed with soil collected from the Nevada Test Site. Atriplex canescens cuttings in triplicate containers were grown in the soil for 70 days. Leaf samples were taken and assayed for stable cesium by neutron activation. The mean coefficient of variation of the triplicate samples was 8.6%. The mean contents in the leaves for the 0, 5, 20, and 50 ppm application rates were 0.0279, 0.58, 5.15, and 24.0 ppm of dry weight, respectively. Although the uptake was consistent and measurable, it was only about 1/400 of what could be expected for an equivalent potassium application. A rate of potassium application of 50 ppm in soil would increase potassium contents around 1% or more of dry weight in the A. canescens plants. This would be a potassium per cesium for the increased uptake of around 2 million. The average potassium per cesium for all plants in Table 1 was 645,000. It is known that cesium is much less available from soil than is potassium (Nishita et al., 1965). The recently applied cesium was evidently available in about the same magnitude as was the original soil cesium.

It is quite apparent then that the availability via plant roots and cycling of ^{137}Cs in ecosystems will be related to the supply of stable cesium in the soil. In some cases dilution could be expected and in other cases concentration could be expected (Nishita et al., 1960, 1962) depending upon the native soil supply.

Summary

Contents of stable cesium in several compartments of desert ecosystems represented at the Nevada Test Site have been determined by neutron activation. Potassium in the same compartments has also been determined and Cs:K discrimination under natural conditions has been evaluated. From compartment sizes some estimates have been made of the rates of cesium cycling through the systems. The rates were low but the stable cesium was circulating. Compartments studied include soil, several different plant species, arthropods, reptiles and mammals. The contents of cesium within compartments were in the nanogram per g of dry weight range. There appeared to be a progressive narrowing of the potassium per cesium ratio going from plants to reptiles and mammals. The addition of stable cesium as CsCl to a soil obtained from the Nevada Test Site resulted in leaf contents in Atriplex canescens of 0.0279, 5.15, and 24.0 ppm per g of dry weight for application rates of 0, 5, 20, and 50 ppm respectively. The applied cesium was slightly more available than was the original soil cesium. One must conclude that stable cesium will have an influence in the cycling of ^{137}Cs.

ACCUMULATION OF LEAD IN ROADSIDE VEGETATION OF MAJOR HIGHWAYS IN SOUTHERN NEVADA

The tetra-ethyl lead additives in vehicle fuels have resulted in a general increase in the lead content of the environment near heavily traveled highway networks and in urban areas. Prince (1957) reported that lead contents of soil near highways in New Jersey ranged between 14 and 96 ppm. During studies to investigate possible correlations between anomalous lead in soils and plants and several diseases in England and Canada, Warren and Delavault (1960) detected the presence of lead in vegetation growing near major highways. Cannon and Bowles (1962) reported the results of a cooperative study by the U.S. Geological Survey and the U.S. Public Health Service. Washed grass near Denver contained as much as 3000 ppm lead (in ash) near major highway intersections, and less than 50 ppm in samples collected 150 meters downwind of the roadway. Vegetables grown within 8 meters of the roadway in upstate New York and in Maryland averaged 80 to 115 ppm lead on the dry weight basis. Singer and Hanson (1969) found that the soil adjacent to 12 highways in the Minneapolis-St. Paul metropolitan area had lead accumulations in the range of 128 to 700 ppm. Most of the lead was deposited within 15 meters from the highways studied.

Chow (1970) studied samples of soil and grass along U.S. Highway 1 near the U.S. Department of Agriculture Plant Industry Station in Beltsville, Maryland and the Baltimore-Washington Parkway at Blandensburg, Maryland. The lead content of the U.S. Highway 1 soil was as much as 403 ppm in the top 5 cm layer and decreased to 60 ppm at 10 to 15 cm depth. The Baltimore-Washington Parkway soil contained 122 and 9 ppm at the corresponding depths. Concentrations of lead in the grasses along these two roads ranged from 20 to 60 ppm (dry tissue). Ault et al. (1970) reported on a detailed study of lead in the environment using the Pb 206/Pb 204 isotopic composition as a natural tracer of lead. Their findings are similar to earlier reports on the lead contamination of soil and vegetation near heavily traveled highways. Beyond 150 meters from the roadways there was no pronounced deposition of lead additives on soil or vegetation from vehicle fuels.

According to Hammond and Aronson (1964) most of the lead from gasoline exhausts is deposited as the highly soluble chlorobromide. However, as Singer and Hanson (1969) indicate, the lead in this chemical form probably reacts with many of the anions and organic and clay complexes present in soils, and thus does not remain in a soluble form. Soluble forms of lead could, however, be incorporated into plants by foliar absorption, thus increasing the levels beyond that which normally would be absorbed via roots from soil. Koeppe and Miller (1970) estimate that each year motor vehicles in the United States liberate approximately 225 x 10^6 kg of particulate lead into the atmosphere. About 50 per cent of this lead is deposited within 30 meters of the roadways and the remainder is scattered over larger areas. Lead accumulation in soils near roads varies with traffic volume and decreases rapidly with distance from the road. In studies of lead effects on corn mitochondrial respiration, Koeppe and Miller (1970) concluded that plants which contain high concentrations of lead are unlikely to be affected by these concentrations due to the precipitation of the lead if sufficient phosphate is present. They further suggest, however, that when effectively high concentrations of lead are reached in our environment, there could be a quick and dramatic reduction in plant growth under conditions of phosphate deficiency.

Marten and Hammond (1966) found that the addition of chelates to soils resulted in a distinct rise in lead concentrations in bromegrass. Of most practical significance, however, was the fact that even the greatest lead concentration (34.5 ppm) was far below the level which would be toxic to animals consuming the grass; at least 150 ppm lead in the total ration dry matter is needed to approach levels observed to be toxic to cattle and horses.

Experimental Results

The highway system converging on the southern entrance to the Nevada Test Site offered an excellent opportunity to investigate the degree to which lead contamination from vehicle fuel might be observed on desert vegetation. The U.S. Highway 95 between Las Vegas and Mercury, Nevada is a two-lane divided highway very heavily traveled by commuting workers. Much of the traffic is by diesel-powered busses but several hundred more gasoline-powered vehicles travel the route each day compared to those which travel beyond Mercury to points north and west of the Test Site.

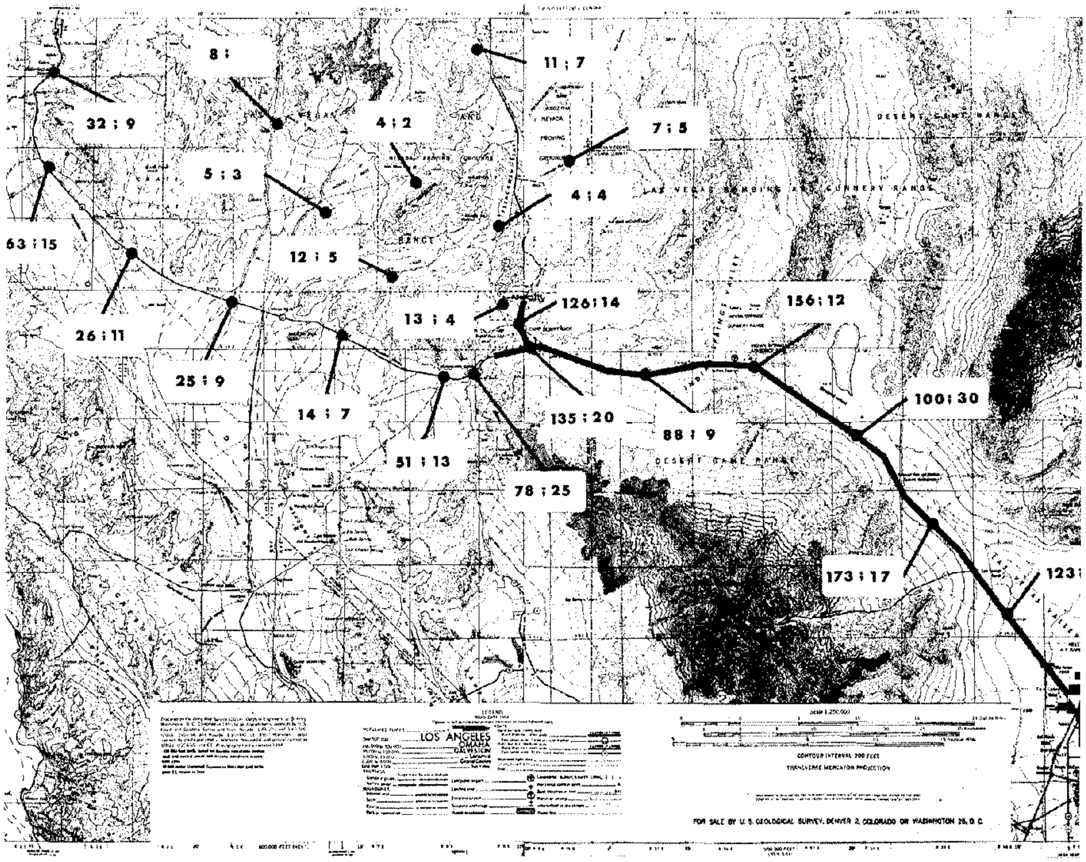
During the 6-month period preceding the collection of vegetation samples, the average daily traffic on U.S. Highway 95 between Las Vegas and Mercury, Nevada, was 3,500 vehicles compared to a daily average of 960 vehicles traveling the section of this highway north from Mercury toward Tonopah, Nevada. These data are based upon information from portable traffic recorder stations supplied by the State of Nevada Department of Highways.

Samples of plant foliage, primarily *Larrea divaricata*, were collected at various points alongside the roadway of U.S. Highway 95 and at field study sites far removed from vehicle traffic. The first samplings were collected in January 1969 at which time most of the plant foliage had been on the shrubs for at least nine months. A second sampling was made in June after the new spring foliage had emerged. Samples of dry plant tissues were analyzed for lead content by emission spectrograph and the results are shown in Figure 1. Foliage samples collected in January alongside the heavily traveled route between Las Vegas and Mercury contained from 88 to 173 ppm lead (dry tissue basis). Samples from the section of U.S. Highway 95 extending northwest to Beatty, Nevada contained from 14 to 63 ppm lead. Samples of plant foliage from field study sites far removed from vehicle traffic contained from 4 to 12 ppm lead. We have not analyzed soil samples for lead content at the sampling sites. We assume that the natural variation in stable lead content could not account for the differences observed and that the higher levels of lead represent deposition from vehicle exhausts. These effects also were apparent in plant foliage sampled in June even though the exposure period on the new foliage was about one-third of the exposure that period plant foliage would receive when sampled in January. The *L. divaricata* shrubs sampled are characteristically evergreen, but their heaviest leaf drop occurs in the early spring just before the new leaf flush develops. The leaf surface has a sticky resin which traps considerable dust. We believe this accounts for the higher levels of lead on foliage sampled in January at the field study sites compared to foliage sampled in June.

Summary

Tetra-ethyl lead additives in vehicle fuel have been shown by several investigators to contaminate the soil and vegetation alongside roadway networks and urban areas. The portion of U.S. Highway 95 between Las Vegas and Mercury, Nevada is heavily traveled compared to the portion of equal distance extending further northwest as the result of daily commuter traffic. Lead contamination was apparent in foliage of desert vegetation collected alongside the roadway, reflecting the variation in traffic volume on the two portions of U.S. Highway 95 that were sampled. Lead contents greater than ten-fold of normal were found in plant foliage alongside the heavily traveled roadway.

Figure 1. A portion of U.S. Highway 95 in southern Nevada showing the heavily traveled route between Las Vegas and Mercury at the south entrance to the Nevada Test Site. The data indicate the lead content in samples of plant foliage collected alongside the roadway and at field study sites (ppm dry tissue). The first value is for samples collected in January 1969; the second is for samples collected in June.



COMPUTER PROGRAM FOR
SELECTING RANDOM SAMPLING LOCI

Quantitative studies of the structure and species composition among plants in an ecosystem often require the selection of random sampling sites over a particular area of interest. Our work in Nevada associated with desert biome studies of the U.S. International Biological Program required the development of a computer program capable of selecting random sampling loci for a generalized study area. Most field workers use standard methods involving some orderly pattern to obtain sample locations for field measurements. If sample locations are to be a statistically valid random sample of a study population, then any location of a given size (e.g. 1 m square) must have an equal chance of being selected. The computer program described here selects a set of random sites within a study area of any prescribed dimension. The size of each sampling site (quadrat) is specified and the program insures that all such quadrats within the total area are equally susceptible to selection. The symbolic language used for the computer program is PL/1 and program development was on the UCLA campus computing network IBM system 360, model 91 computer. A system random number generating function is used to select the random number pairs whose intersections identify quadrat locations within the study area. The program was designed so that sampling quadrats could be randomly distributed over the entire area or stratified according to any desired pattern.

Figure 1. Scaled, schematic diagram of the I.B.P. study area enclosed in a rectangle in order to define boundaries and convert locations to map coordinates.

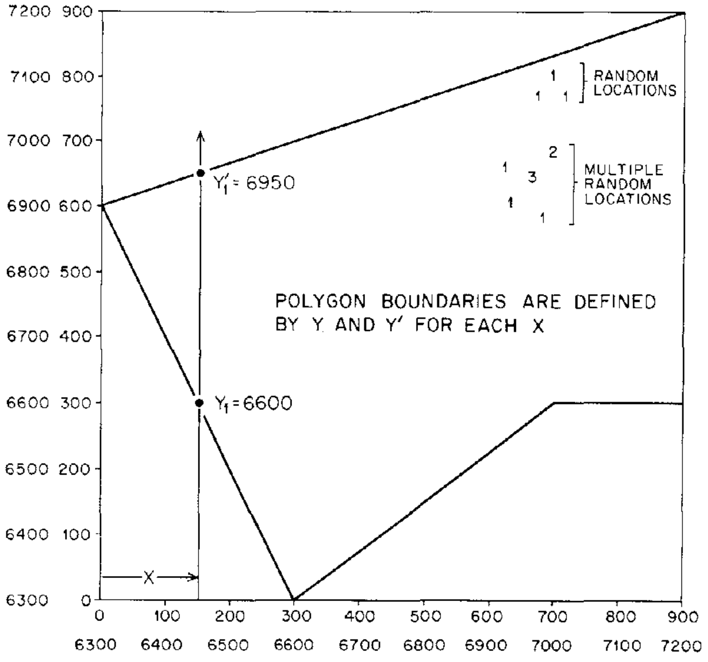


Table 1. Data card pertaining to values of X_1 and the associated Y intersections.

Columns on card	Descriptions
1-2	Number of pairs of intersections.
4-8	First intersection encountered by line.
10-14	Second intersection encountered by line.
16-20 etc.	Additional intersections encountered (occurs only if complex shape of polygon results in a line entering the polygon more than once).

Methods

The study area is first drawn to scale on graph paper and the resulting polygon enclosed in a rectangle of minimum size (Figure 1). Two of the adjoining boundaries (of lengths a and b, respectively) of the enclosing rectangle are chosen as conventional X and Y axes for a system of coordinates capable of defining any point within the rectangle. The basis for choice of axes should insure minimum X and Y values at the lower left rectangle origin. It is next necessary to define the boundaries of the study area lying within the enclosed rectangle. The X and Y axes are marked off in equidistant intervals. The size of the interval (i), selected at the discretion of the investigator, should be small enough to insure good resolution of the study area boundaries. The boundaries may now be specified on a set of data cards. There is one data card for each value of X, i.e., for $X = 0$, $X = i$, $X = 2i \ldots X = a-i$. Each data card of this set specifies the number of times a line extended from the X-axis intersects the boundaries of the study area (usually only twice), and gives the respective Y values for each intersection (Figure 1). Table 1 illustrates the data card pertaining to values of X_i and the associated Y intersections. The data deck is ordered in ascending values of X. One additional data control card; placed at the beginning of the data deck, is needed in order to run the program (Table 2). This card gives parameters relating to the specific study area and the number of random sampling sites desired. As noted previously, the X and Y axes of the rectangle enclosing the study area were arbitrarily scaled, at equal integers, from zero to a and b. This scale will usually not coincide with the values actually assigned to the study area in the field. Hence, the X and Y coordinates of the sampling sites generated by the program will not match the field coordinates unless they are appropriately adjusted. To make this adjustment the first two fields of the data control

Table 2. Control data card for execution of program.

Columns on cards	Description
1-6	X amount to be added to graph zero location.
8-13	Y amount to be added to graph zero location.
15-16	X axis (i) interval.
18-22	Number of data cards describing plot.
24-28	Number of random values desired.
30-34	Starting point for random number generating function.
36-40	Distance of X baseline.
42-46	Distance of Y baseline.

card give the amount by which the X and Y coordinates must be increased to correspond with field coordinates. It will be observed that each X and Y coordinate must be increased by 6300 (Figure 1, map coordinates) to achieve this correspondence. The third field on the data control card gives the X axis interval (i) selected. The fourth field gives the number of cards in the data deck (defining the boundaries of the study area). The number of random points (X-Y intersections) desired is given in the fifth field. The sixth field is any four-digit number chosen arbitrarily as a starting point for the random number genarating function. The last two fields give the lengths (a and b) of the X and Y axes respectively.

Major program functions are listed below:

a. Read in the data deck.

b. Define the study area boundary.

c. Select random values of X and Y pairs. Test the intersection of these paired values to determine whether they fall within the study area or on its boundary. Valid locations are counted and retained. Iteration of the process continues until the requested number of random points is completed.

d. Sort paired X and Y values in ascending order of their Y value. This operation is for the convenience of the investigater in locating the random sampling sites.

c. Print paired values of random X and Y in ascending order of X value (Table 3).

Figure 2. Computer-plotted graph of the Rock Valley I. B. P. validation site with random sampling locations.

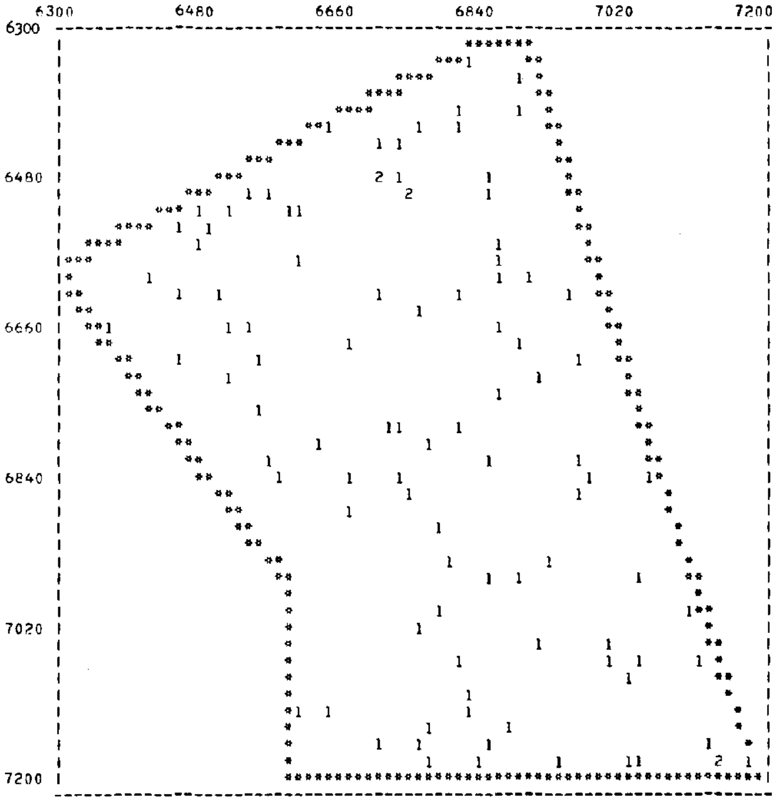


Table 3. Random cartesian locations for Rock Valley I. B. P. validation site.

No.	X location	Y location	No.	X location	Y location
1	6349	6839	51	6786	6747
2	6375	6894	52	6791	6820
3	6401	6815	53	6794	6735
4	6401	6904	54	6802	6780
5	6422	6764	55	6814	6635
6	6427	6827	56	6821	6855
7	6438	6659	57	6825	6970
8	6457	6718	58	6840	6575
9	6457	6746	59	6843	6684
10	6495	6854	60	6844	6595
11	6495	6723	61	6845	7069
12	6497	6744	62	6854	6743
13	6497	6724	63	6857	6982
14	6502	6760	64	6877	6760
15	6503	6857	65	6878	6978
16	6505	6756	66	6891	6685
17	6508	6546	67	6908	6800
18	6510	6577	68	6949	6939
19	6522	6608	69	6952	6807
20	6529	6482	70	6970	6859
21	6532	6611	71	6974	7049
22	6534	6528	72	6980	6893
23	6552	6466	73	7009	7120
24	6552	6500	74	7012	6801
25	6565	6873	75	7040	6768
26	6571	6486	76	7051	7014
27	6595	6616	77	7055	6926
28	6600	6868	78	7061	7014
29	6609	6912	79	7072	6823
30	6615	6418	80	7073	7126
31	6615	6874	81	7078	7050
32	6622	6712	82	7091	7038
33	6624	6462	83	7102	6828
34	6629	6513	84	7130	6831
35	6637	6961	85	7135	6614
36	6638	6819	86	7139	6657
37	6653	6773	87	7151	6890
38	6665	6366	88	7155	6776
39	6672	6872	89	7163	6715
40	6673	6545	90	7167	7148
41	6677	6519	91	7169	6764
42	6683	6683	92	7171	6858
43	6694	6897	93	7182	7157
44	6707	6971	94	7186	6777
45	6715	6570	95	7188	6949
46	6715	6463	96	7188	7038
47	6721	6929	97	7194	7052
48	6729	6525	98	7195	7188
49	6760	6870	99	7196	7157
50	6771	6565	100	7197	6848

f. Depict a graph (Figure 2) of the enclosing rectangle and the study area, with sampling loci superimposed. Locations are ordinarily indicated simply by the numeral one. However, if several sampling points are so close together that the computer printing resolution cannot resolve the difference, a larger number is printed. This numeral indicates the number of closely aggregated sampling points (Figure 1).

Conclusions

The program intent is to introduce a computerized method of selecting random sampling points for use in field studies. The information requirements are minimal and the size or shape of the study area is irrelevant as long as it may be drawn to scale on graph paper. The data cards contain Y-axis intersections for values of X incremented by some fixed interval (i) from 0 to a-i. All additional requirements are contained on one data control card. Random quadrat dimensions should be integer values, as should the selected interval (i) between values of X. Stratified sampling of a large field plot may be accomplished by submitting one subdivision at a time for random number selection.

H. W. Kaaz is the principal author of this report.

SOME IMPORTANT ASPECTS OF PLANT BEHAVIOR IN THE DESERT

The Nevada Test Site represents a transition zone between the Great Basin Desert and the Mojave Desert. Much of the behavior and distribution of the shrub species in the Nevada Test Site is related to this transition. Factors obviously influencing the distribution of shrubs include soil moisture, soil and air temperatures, amount of freezing, soil pH, soluble salts including sodium salts and gypsum, slope, parent material, the calcareous and noncalcareous nature of soil, soil structure and aeration, drainage, underlying hardpan caliche layers and possibly allelopathy. Whether or not any of these factors are more important than others is difficult to determine because under certain conditions each can be the dominant factor. Interactions among the factors undoubtedly are the most common cause of differences in vegetation mosaics. Continuing studies are being made of these factors and their interactions by many groups of workers.

The plant species present at the Nevada Test Site represent a remarkable array of adaptations to survival under desert conditions. Studies to date have probably identified only a small portion of these mechanisms. Some of those of considerable interest include the following:

1. Rapid rate of depth of rooting of seedlings of Larrea divaricata (see page 121) and Artemisia tridentata (see page 95) is remarkable. Elongation at a rate of $2\frac{1}{2}$ cm per day almost immediately after germination insures potential use of as much soil moisture as is available.

2. Germination of seeds of shrubs in late summer (see page 279) following summer rains makes possible survival through the winter and the next spring before the seedling needs to endure summer drought.

3. A low soil temperature requirement for breaking dormancy and high temperature dormancy (see pages 112 and 143) permits most shrubs to complete a seasonal cycle while the season is cool and when soil moisture is plentiful.

4. C_4-dicarboxylic acid pathway of photosynthesis (see page 331) enables some plants to grow rapidly under high temperature and low soil moisture conditions. More rapid growth within a given period of time enables plants to complete a cycle during the period when soil moisture or other conditions are favorable.

5. Ease of leaf abscission makes it possible for some species to avoid dehydration to the lethal point (see page 140 and 157). Lycium andersonii and Franseria dumosa leaves abscise easily and abscission can be induced by hot dry winds.

6. Leaf structure (leaf dissection) and size (smallness) (see page 303) leads to easy heat dissipation so that leaves do not easily acquire sufficient heat to cause death.

7. Adaptations to permit photosynthesis at low leaf water contents as for L. divaricata (see page 127) and Krameria parvifolia (see page 164) permit survival under conditions for which most ordinary plants die.

8. Of the various mechanisms of adaptation in seed germination, that of extremely rapid germination (see page 148) is one of the most remarkable.

Seed of the Salsola species literally explode in minutes when moisture and temperature are favorable and the seedling achieves establishment by rapid elongation of cells previously divided. The embryo is a fully differentiated seedling.

9. Work must be done by leaves to obtain water from almost dry soil and one of the adaptive mechanisms to accomplish this is an increased differential temperature between the leaf and its environment. This is achieved by stomatal regulation (see pages 312 and 325).

10. Some species obtain water during periods of rain and retain it by adaptive insulating structures for use in dry seasons as in some cacti.

11. In summer months some species may be able to use vapor water (see page 115). Vapor may precipitate in soil due to temperature differentials.

12. Some species avoid competition by producing chemicals which prevent other species from competing with them (see page 310).

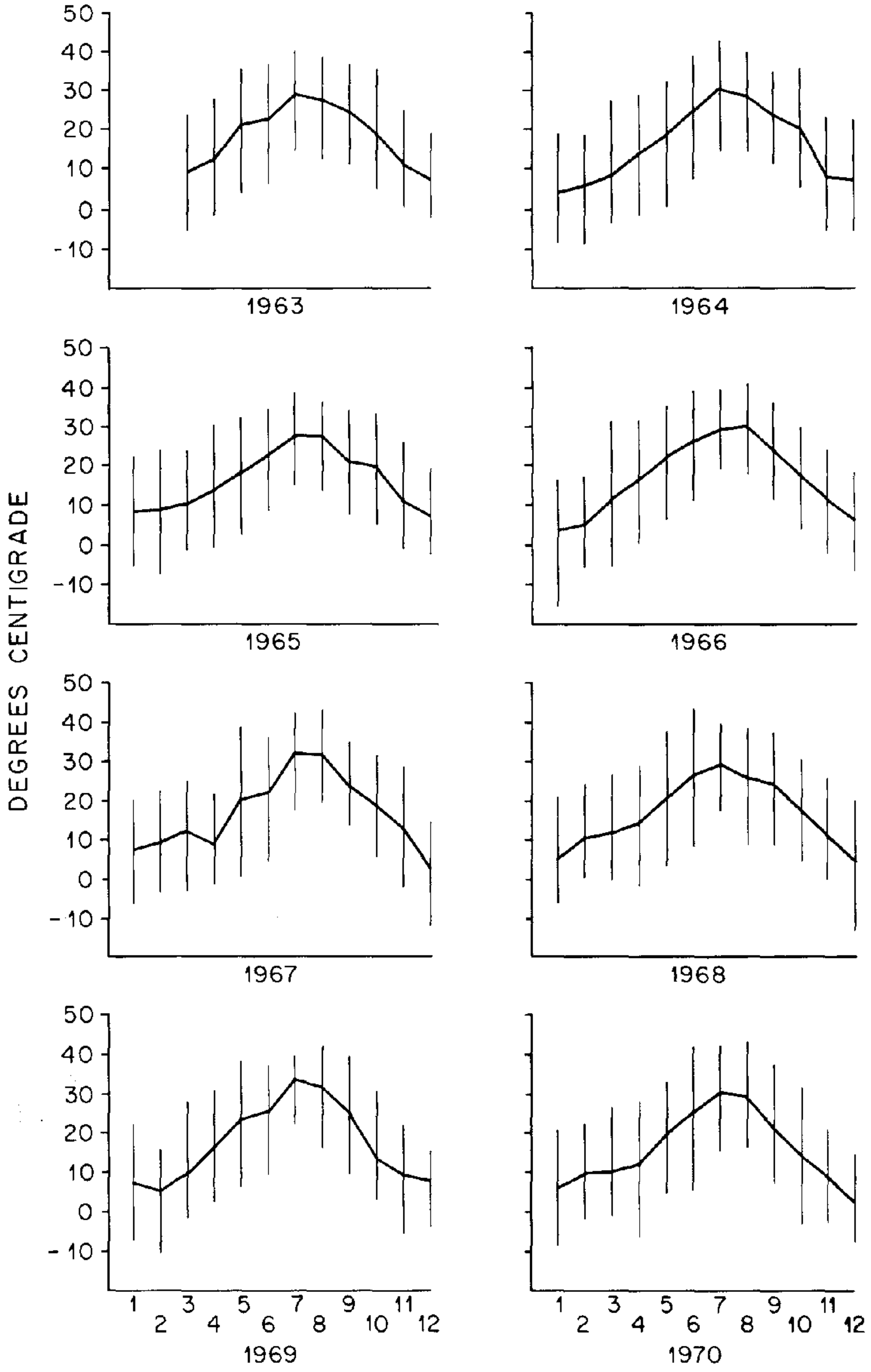
13. Some species are structurally arranged so that rainfall when moderate is channeled down the branches and enters the base of the stem (see page 328). Soil near the base of a stem of shrubs in the desert is usually more permeable to water because of a long-time build up of soil organic matter. Water striking the soil under many desert conditions is likely to run off rather than penetrate the soil.

14. Plant reestablishment by vegetative means is a survival mechanism (see pages 105 and 165). Individual shrubs do not live forever and establishment of seedlings is usually a precarious matter with several factors needing to be correlated to achieve it. A most common means of shrub propagation is for crowns to break up into several individual plants. When roots are injured some species readily initiate shoots from the cut roots (see page 122).

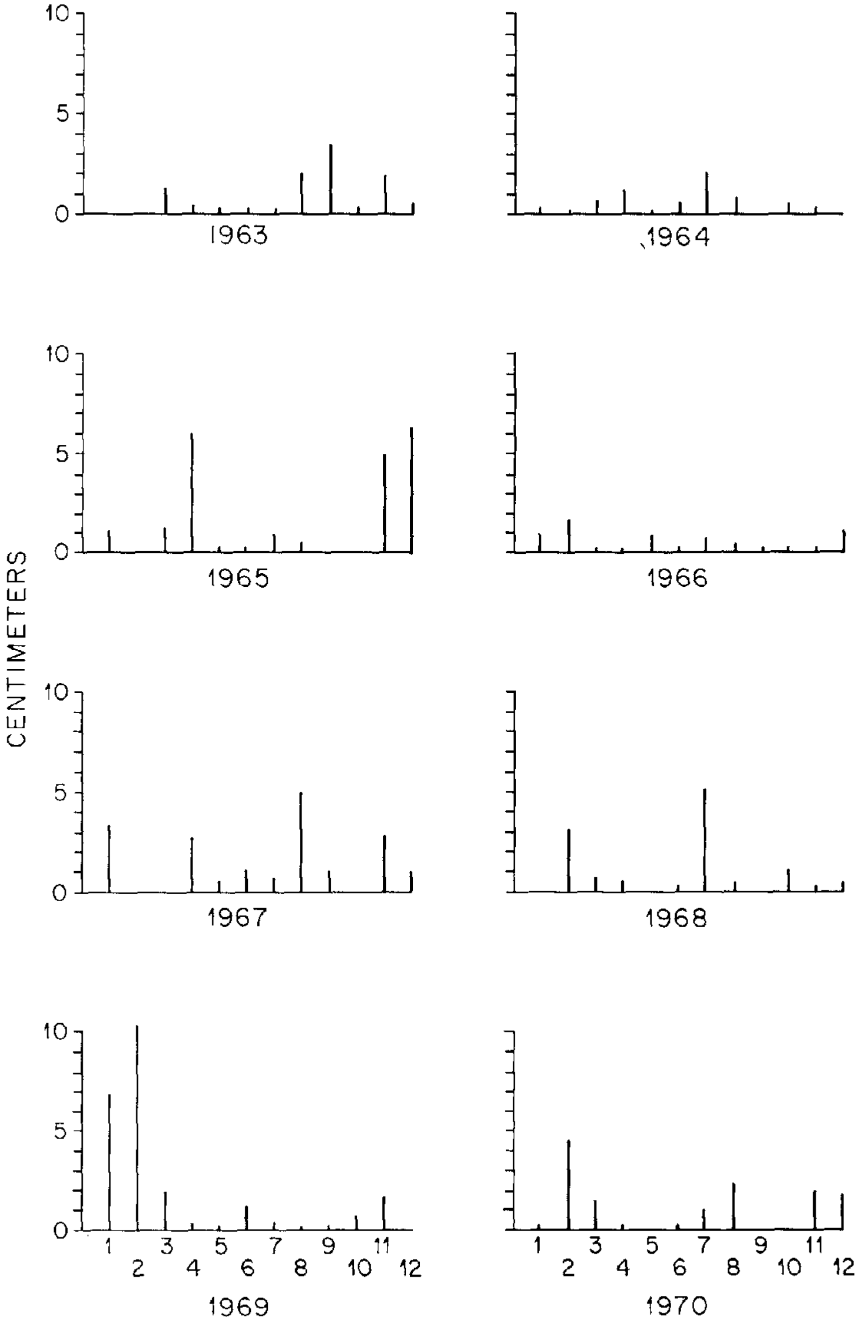
Community synthesis is perhaps the most important consideration for biological survival under desert conditions. Shrubs in the northern Mojave Desert portion of the Test Site are generally associated together in clumps and seldom are there pure stands of any shrub. There are some, however. The relationships among the individuals within a clump appear to be mostly random (see page 205). The soil within a clump is just a good place for a new plant to grow in. Centuries of organic matter decomposition and animal activity insure this. Animal populations appear to use most of the annual seed production in the ecosystems at the Nevada Test Site. Populations adjust rapidly to changing food supply (Beatley, 1970). Calculations indicate that animal populations easily could consume essentially 100% of the annual seed production. This most certainly is not achieved in nature, however, because of the numerous seedling germinations. The animal populations do achieve a degree of regulation over the plant populations, however, but use of seed for food is not the only factor involved.

There is a large amount of year to year variation in environmental characteristics of the areas under study and, consequently, the year to year variability in biological responses is also great (see page 230). For example, in some extremely dry years seed production is very inefficient and can be relatively low in proportion to the vegetative production. All these factors contribute to the final character of our desert ecosystems and imply that there is yet much to be learned concerning them.

APPENDIX



Rock Valley air temperature



Rock Valley precipitation

ROCK VALLEY PROJECT: PLANS FOR THE STUDY OF RADIATION EFFECTS ON PLANT POPULATIONS

(W. E. Martin, December 1963)

Beginning early in 1964, a circular area of about 9 hectares in Rock Valley at the Nevada Test Site will be exposed to gamma radiation from ^{137}Cs at a chronic, relatively uniform level of about 4 R per day. The gamma field and two of the three nearby control plots of equal area are enclosed by rodent-proof fences. The third control plot is unfenced.

The major objective of this experiment is to study the effects of chronic, uniform, low level gamma radiation on small mammal populations in their natural environments. Plans are also being made to utilize the same experimental facilities to study the effects of chronic radiation on desert plant populations.

It is expected that a careful comparison of the behavior (seasonal development, growth of photosynthetic tissue, and reproductive success) of plant populations in the gamma field with that of similar populations in one or more of the control plots in the same vicinity will: (1) contribute to the animal studies by broadening our general understanding of radiation effects on desert ecosystems, and (2) contribute to our meager knowledge of the effects of ionizing radiation on the ecology of plant communities.

Description of the Study Area

A. Topography

The gamma field and control plots in which these studies will be conducted are located on a broad alluvial fan bordering the northwest-side of the Specter Range (*ca* 36° 40' N x 116° 5' W). The slope within plots ranges from 3% to 5%, and the initial drainage is toward the northwest. Subsequent drainage from Rock Valley is southwesterly into the Amargosa Desert east of Lathrop Wells, Nevada.

B. Soil Types

The soils in the study area are derived from a heterogeneous, highly calcareous alluvium composed primarily of Cambrian limestones from the Specter Range (Johnson & Hibbard, 1957). On the steeper slopes above the study area and in the shallow drainage channels which traverse the study area, there has been no profile development. The soils on gentler slopes have characteristic profiles.

Two soil types have been distinguished and their distribution has been described (Table 1) on the basis of surface and profile characteristics. The "mature" soil of this area is characterized by desert pavement and the "young" soil is characterized by the absence of desert pavement. The surface of the desert pavement soil is composed of stones (1 to 4 cm diameter) lying close together with their longer axes on the horizontal plane to form a smooth, hard surface which is virtually devoid of plant life. The underside of each stone is coated with lime, and the upper sides of non-calcareous stones are usually coated with desert varnish. The desert pavement stones are embedded in a thin (1 to 8 cm) layer of loam which is essentially free of stones and has a definite vesicular structure (Springer, 1958). The surface of "young" alluvium is also stoney, but the stones do not lie on the same plane and many have lime encrustations on exposed surfaces. The stoneless, vesicular layer (A_V)

is usually lacking.

The profiles of both soil types are characterized by the downward leaching and deposition of lime and other soluble minerals. Stones in the A-horizon have lime encrustations only on their undersides. Stones in the B-horizon have lime coatings on all surfaces, and the matrix soil usually has a weak blocky structure. The frequency of lime seams and nodules increases with increasing depth, and heavy lime deposits, generally below (45 to 60 cm), form a massive but weakly cemented layer of caliche (C_{ca}).

The texture and certain chemical properties of soil collected at "desert pavement" and "young alluvium" sites appear in Table 1. These preliminary analyses seem to indicate a fairly high degree of similarity between the two types.

C. Vegetation

The vegetation of the study area is more or less characteristic of the Northern Mojave Desert (Jaeger, 1957; Allred et al., 1963). A preliminary comparison of shrub populations in the proposed gamma field with those in the nearest fenced control plot (Table 2) has indicated a fairly high degree of similarity.

Eight out of the 10 species encountered on a total (25 transects x 15 m) 375 m of line transects in each plot were found in both plots. The total shrub population (ca. 4272 shrubs per hectare) in the gamma field is somewhat smaller than that of the control plot (ca. 5586 shrubs per hectare), but this difference can be attributed largely to the greater prevalence of desert pavement occurring in the gamma field. The importance values of the two characteristic species, Larrea divaricata and Franseria dumosa, are virtually the same in each plot. The coefficient of similarity, based on importance values, was 81%. None of the differences demonstrated by this comparison appear to be great enough to invalidate the comparison of shrub populations in the gamma field with populations of similar species in one or more of the control plots.

The herbaceous flora of Rock Valley (Beatley, 1962) includes one perennial grass (Oryzopsis hymenoides) and more than 50 species of herbaceous annuals. Detailed information concerning the occurrence and abundance of herbaceous species in the gamma field and control plots has not yet been collected.

D. Phenology

The seasonal development, growth and flowering of both the herbaceous and the woody species in Rock Valley are closely regulated by seasonal variations in rainfall and temperature (Beatley, 1963). Most desert annuals in this area are known to germinate shortly after the first rainfall of one-half inch or more between September and December. These species pass the colder months as seedlings or rosettes; and then complete their growth, flower, set seed and die the following spring (March through June).

Most of the shrub species seem to follow a similar pattern. Leaves and flowers are produced during the spring or early summer. By midsummer, most shrubs are virtually leafless and either dormant or semi-dormant, but the first heavy rains of late summer or fall are usually followed by a second flush of leaf development and flowering which may continue until cold weather sets in.

Possible Effects of Chronic Radiation on Plant Populations

A. Previous Studies at the Nevada Test Site

Much of the vegetation of Yucca Flat has been exposed to air blast, ground

Table 1. Physical and chemical properties of the major soil types, "desert pavement" and "young alluvium" in the Rock Valley Study area at the Nevada Test Site.

Soil type	Horizon (tentative)	Depth (cm)	Mechanical analyses				Chemical analyses				
			% sand	% silt	% clay	pH	% $SiCO_3$	% Ca	% Fe	K (ppm)	Na (ppm)
"Desert pavement" (loam) (Type II)	A_1	0-1¼	60.1	33.3	6.6	8.1	49.5	8.5	6.5	17	10
	A_v*	1¼-5	44.4	45.8	9.8	9.1	52.9	7.4	4.9	73	12
	A_2	5-15¼	50.9	39.3	9.8	8.7	51.9	9.1	8.5	20	15
	B**	15¼-30½	54.1	39.3	6.6	8.6	52.3	8.9	6.6	25	12
	C_{ca}***	30½-61	54.2	32.7	13.1	8.6	49.9	10.1	5.2	31	12
"Young alluvium" (sandy loam) (Type I)	A_1	0-5	65.9	29.2	4.9	8.7	60.6	4.8	6.1	8	9
	A_2	5-15¼	61.1	32.4	6.5	8.8	62.0	6.1	6.4	17	10
	B**	15¼-30½	67.5	26.0	6.5	8.9	—	7.4	4.5	21	8
	C_{ca}***	30½-61	75.4	19.7	4.9	8.9	48.9	13.1	4.5	21	10

*The A_v horizon is an essentially stoneless layer of loam having a vesicular structure. The formation of such strata has been discussed by Springer (1958).

**The B horizon has a blocky structure and stones with lime encrustations on all surfaces.

***The C_{ca} horizon is a massive but weakly cemented layer of caliche.

shock, thermal radiation and ionizing radiation from nuclear detonations; but none of the effects thus far observed can be attributed unequivocally to ionizing radiation. Shields and Wells (1962) have described the zonation of plants around several ground zero sites in Yucca Flat. While they concede that exposure to ionizing radiation may have had some effect on this vegetation, they finally concluded that all the effects they were able to observe after several years of recovery could be attributed to air blasts, ground shock, and thermal radiation. More recently, Martin (1963) has described the effects of an underground nuclear detonation (Project Sedan) on vegetation at the north end of Yucca Flat. To a distance of 760 m from ground zero, the vegetation was completely destroyed by air blast and/or covered by radioactive throwout deposits. Between 760 m and about 1525 m from ground zero, shrubs were severely to moderately damaged by air blast and exposed to cumulative gamma doses between 1000 and 10,000 R. Between 1525 m and 3050 m from ground zero, plants were not damaged by blast but were exposed to heavy deposits of radioactive dust derived from the base-surge cloud. In one area about 3050 m southeast of ground zero, a population of L. divaricata was exposed, over a 2-month period, to cumulative gamma doses of 5000 to 6000 R. Subsequently, these plants lost all their foliage; but now, about 17 months after the detonation, about two thirds of the defoliated plants have produced new leafy branches from lateral buds or from adventitious buds which developed near the bases of the larger branches. These effects cannot be attributed unequivocally to radiation because the potential effects of dust alone are not yet known. We plan next summer to observe the effects of heavy dust deposition on non-irradiated specimens of Larrea.

In general, the 40-day cumulative gamma doses at distances greater than 3050 m from Sedan ground zero were less than 4000 R., and this is well below the dose (7500 rads) required to kill pine trees (Pedigo, 1963) which are thought to be much more sensitive to radiation damage than most other plant species. From this rather limited experience, it may be reasonable to assume that plants which were not damaged by air blast or ground shock from the past nuclear detonations in Yucca Flat were not generally exposed to lethal doses of gamma radiation. Those plants which may have been damaged by sub-lethal doses of gamma or gamma-neutron radiation have subsequently recovered and now appear quite normal. While this reasoning is somewhat speculative, it could explain the apparent absence of radiation damage to the much bombed and frequently exposed vegetation of Yucca and Frenchman Flats at the Nevada Test Site.

B. Experimental Studies at the Brookhaven National Laboratory

A. H. Sparrow and his colleagues (Sparrow et al., 1961a, and b; Sparrow and Evans, 1961; Evans and Sparrow, 1961) at Brookhaven National Laboratory have shown that the major site of radiation damage to plants is the cell nucleus, and that most radiation effects on growth and development can be related to the doses absorbed by the nuclei of meristematic cells. The results of experiments involving the exposure of various species of herbaceous annuals to chronic gamma radiation have shown that the frequency of chromosomal aberrations, the frequency of somatic mutations, and the degree of growth inhibition at a given dose rate are closely related to the nuclear volumes (and chromosome numbers) of cells in apical meristems. In summarizing these results, Sparrow has shown that the regression of average chromosome volume (nuclear volume per chromosome number) on the chronic dose rate required to cause severe growth inhibition (less than 20% of controls) is approximately -0.93. A regression coefficient of -1.0 would indicate that the product of chromosome volume and the chronic dose rate required to produce severe growth inhibition

Table 2. Comparison between shrub populations in the proposed gamma field (Plot B) and those in the nearest control plot (A) in the Rock Valley Study Area, Nevada Test Site, based on the study of 25 line-intercept transects, 15 m per transect, in each plot.

Shrub species	Plot	T	N	ID	%F	%D	%C	IV(1)
Coleogyne ramosissima	A:	1	1	0.4	1.5	0.5	0.3	2.3
	B:	4	6	2.2	4.4	3.4	2.3	10.1
Dalea fremontii	A:	0	0	0.0	0.0	0.0	0.0	0.0
	B:	1	1	0.4	1.1	0.6	0.4	2.1
Ephedra nevadensis	A:	9	11	5.6	9.5	5.7	5.2	20.4
	B:	13	23	8.2	14.1	13.1	8.4	35.6
Eurotia lanata	A:	1	2	0.7	1.5	1.0	0.7	3.2
	B:	3	5	0.9	3.3	2.9	1.5	7.7
Franseria dumosa	A:	16	44	18.9	16.8	22.8	17.7	57.3
	B:	17	46	17.8	18.5	26.2	18.2	62.9
Grayia spinosa	A:	2	3	1.5	2.1	1.6	1.4	5.1
	B:	4	6	4.5	4.4	3.4	4.6	12.4
Krameria parvifolia	A:	21	38	13.3	22.0	19.7	12.5	54.2
	B:	4	5	2.2	4.4	2.9	2.3	9.6
Larrea divaricata	A:	21	44	31.1	22.0	22.8	29.2	74.0
	B:	19	38	29.7	20.6	21.7	30.4	72.7
Lycium andersonii	A:	24	50	35.1	25.2	25.9	33.0	84.1
	B:	17	30	20.7	18.5	17.1	21.2	56.8
Lycium pallidum	A:	0	0	0.0	0.0	0.0	0.0	0.0
	B:	10	15	10.4	10.9	8.6	10.7	30.2
Totals	A:	95	193	106.9	100.6	100.0	100.0	100.0
	B:	92	175	98.2	100.2	100.0	100.0	100.0
Coefficient of Similarity:(2)		74%	73%	77%	75%	73%	78%	81%

(1) T = number of transects on which species was encountered.
N = number of plants encountered on a total of 25 transects.
ID = intercept distance (meters) per 25 transects.
%F = relative frequency, %D = relative density, %C = relative cover.
IV = %F + %D + %C (Importance Value).

(2) Coefficient of Similarity = 2w/a+b, where a and b are the sums of recorded values for plots A and B and w is the sum of the smaller values in each pair.

Additional Data	Plot A	Plot B
Per cent of total area covered by plants	28.8%	26.4%
Total number of shrubs per hectare	5586	4272

is a constant. Other studies (Sparrow et al., 1961) have shown that the chronic dose rates required to produce other effects are roughly proportional to those required to produce severe growth inhibition (Sparrow and Woodwell, 1962).

From these studies, Sparrow and Woodwell (1962) have developed a method of predicting the sensitivities of plant species to chronic radiation. Prior to the chronic irradiation of a near-climax oak-pine forest at Brookhaven National Laboratory, this method was used (Woodwell and Sparrow, 1962) to predict the responses of woody perennials. They based their predictions primarily on the nuclear volume and growth inhibition relationships revealed by studies of annuals grown under cultivation in a gamma field. Measurements made about 8 months after the beginning of chronic irradiation indicated that severe growth inhibition was induced by chronic dose rates several times lower than had been predicted.

Apparently, the trees and shrubs growing under natural conditions in the forest community were relatively more sensitive to radiation damage than were comparable herbaceous species growing under cultivation in the gamma garden. Perhaps, these results can be explained as follows: (1) The irradiation of forest plants began during their dormant period, and the average dose absorbed per nucleus in the dormant meristems was higher than would have been absorbed by the nuclei of the actively growing meristems of herbaceous annuals under cultivation. (2) The plants growing in the forest community were probably subjected to greater physiological and environmental stresses than the plants grown in the gamma garden. (3) The average period of exposure for herbaceous plants was only 3 months (10 to16 weeks), but the forest was exposed for 8 months before measurements were made. Woodwell and Sparrow (1962) concluded that determinations of nuclear volumes and chromosome numbers provide a basis for predicting the radiosensitivity of plant species "within broad limits" but "further refinements of the method are needed."

The nuclear volumes of deciduous trees and shrubs in the Brookhaven National Laboratory forest and of ten shrub species in Rock Valley are given in Table 3. The results reported by Woodwell and Sparrow indicate that the apical meristems (both terminal and lateral) of all the woody species in the

Table 3. Nuclear volumes of trees and shrubs in the Brookhaven National Laboratory forest (from Woodwell and Sparrow, 1962) and of shrub species in Rock Valley, Nevada Test Site (N. R. French).

Brookhaven National Laboratory, N.Y.		Rock Valley Area, Nevada Test Site	
Species	Nuc. vol. (μ^3)	Species	Nuc. vol. (μ^3)
Quercus alba	155	*Ephedra nevadensis*	633
		Lycium andersonii	187
Quercus illicifolia	105	*Krameria parvifolia*	136
		Lycium pallidum	91
Quercus coccinea	85	*Eurotia lanata*	82
		Franseria dumosa	70
Vaccinium angustifolium	60	*Dalea fremontii*	53
		Grayia spinosa	47
Vaccinium vacillans	45	*Larrea divaricata*	46(?)
		Coleogyne ramosissima	30
Gaylussacia baccata	32		

(?) indicates tentative determinations

Brookhaven National Laboratory forest were killed by 8 months exposure to chronic dose rates over 100 R per day, but the predicted LD_{90} for Gaylussacia baccata and Vaccinium species was about 500 R per day. The chronic dose rates required to produce about 50% growth inhibition were about 4 R per day for Quercus coccinea and Quercus illicifolia, about 10 R per day for Quercus alba, and 15 to 20 R per day for the ericaceous shrubs (Vaccinium species and Gaylussacia baccata).

If the Rock Valley species' response to chronic radiation is analagous to that of similar species observed in the Brookhaven National Laboratory forest, a year's exposure to 4 R per day might produce moderate to severe growth inhibition in those species having nuclear volumes of 80 cubic microns or more, but the growth of species with smaller nuclear volumes would probably appear normal. If the effects of environmental stress are greater in Rock Valley than in the Brookhaven National Laboratory forest, a chronic dose rate of 4 R per day in Rock Valley might be equivalent to a chronic dose rate of 8 to 12 R per day in the Brookhaven National Laboratory forest experiment. Obviously, these considerations are highly speculative. The behavior of a desert shrub community exposed to chronic radiation may be quite different from that of a deciduous forest, and it seems important to stress the uncertainties of any predictions we might make at this time.

C. Experimental Studies at Dawsonville, Georgia, and Emory University

R. B. Platt and his students at Emory University have also studied the effects of ionizing radiation on natural plant communities. Their results provide an additional basis for speculations concerning the possible effects of chronic radiation on plant populations in Rock Valley.

During the summers of 1958 and 1959, several oak, hickory, and pine stands near Dawsonville, Georgia were exposed to acute gamma-neutron doses from a partially shielded reactor (Cowan and Platt, 1963). During the autumn following irradiation, the nearby pine trees turned brown and lost their foliage, and the foliage of deciduous trees exposed to radiation was lost earlier than that of similar trees which had not been irradiated. The following year, winter dormancy was prolonged. Many buds failed to develop, and those which did develop produced less terminal growth and fewer leaves than did non-irradiated buds of the same species. Most of the leaves produced by radiation damaged buds were deformed beyond recognition. In general, pine appeared to be more sensitive than hickory which was more sensitive than oak (Platt, 1963).

Forest stands close to the reactor were apparently killed by high radiation doses (over 10,000 R). During 1960 and 1961, herbaceous species characteristic of old-field succession in this area became established under the defoliated trees; but by the summer of 1963, these had been largely replaced by abundant coppice growth from the underground structures of trees and shrubs.

All the readily observable effects of radiation on trees and shrubs in this area could be attributed to the damage of dormant or developing buds. The underground parts of woody plants, shielded from radiation, were not killed and have been able to produce new growth which appears to be normal (McGinnis, 1963).

Studies by McCormick and Platt (1962), made in the gamma field on the Emory campus, have confirmed the importance of physiological stress in determining a plant's apparent sensitivity to radiation damage. In these studies, plants were first exposed to radiation and then compared with non-irradiated controls which were grown in the greenhouse under optimal conditions or else the irradiated and non-irradiated plants were subjected to shading, drought, or heat treatments. In most cases, the plants placed in optimal environments after being irradiated showed little or no response to the radiation treatments; but the tolerance of irradiated plants to shading, drought and heat treatments was lower than that of non-irradiated plants of the same species. McCormick and Platt concluded that "the effects of radiation (on plants) were not expressed until (their) physiological tolerances were challenged." (It is interesting to note that Woodwell and Miller, 1963, came to a similar conclusion after studying the effects of chronic low level gamma radiation on the radial growth of Pinus rigida.)

D. General Principles Concerning Radiation Effects on Plants

From the results of the studies briefly reviewed above, I believe it is reasonable to suggest that several principles are apparent. A brief statement of these principles should provide useful guidelines in planning to study the effects of radiation on plant populations in Rock Valley.

1. The major site of radiation damage to plants is the cell nucleus; and the amount of damage suffered by a given cell nucleus exposed to chronic radiation is related to those factors which determine the absorbed dose per nucleus or per chromosome.

2. Because the average life span (interphase) of cell nuclei in an actively growing meristematic tissue is shorter than that of cell nuclei in a dormant meristem, active meristems are less susceptible to the effects of chronic radiation. This may explain the observation that woody perennials are apparently more sensitive than herbaceous annuals having the same nuclear characteristics.

3. Under given environmental conditions, the relative radiosensitivities of the several species' populations comprising a plant community (or synusium) appear to be related to the nuclear volumes (and average chromosome volumes) of their apical meristems.

4 When exposed to a given chronic level of radiation, the apparent sensitivities of the individual plants comprising a species' population can be expected to vary in relation to the physiological stresses imposed on each plant by its immediate environment. Therefore, radiation plus another potentially limiting factor such as low temperature, high temperature, or inadequate moisture may have synergistic effects on physiological processes controlled by cell nuclei and involved in development, growth, reproduction, etc.

5. Most of the readily observable and conveniently measurable effects of chronic radiation on woody perennials are, apparently, the results of damage to the nuclei of dormant or active meristematic cells. At sublethal dose rates, such damage may result in a reduction of growth and photosynthetic capacity and a reduction of reproductive capacity.

E. Possible Effects of Chronic Radiation (4 R per day) and other Environmental Factors on the Perennating Buds of Desert Shrubs

Some of the possible effects of chronic radiation on dormant or active buds are listed below. These are the kinds of potentially significant effects we have been led to expect from the Rock Valley experiment. Our general plan of procedure will be to make periodic observations, in the gamma field and in one or more of the three control plots, which should enable us to detect and measure these kinds of effects if they occur.

1. Reduction of growth and photosynthetic potential
   a. The dormant meristems in buds may be killed and fail to develop.
   b. The winter and/or summer dormancy of irradiated buds may be

prolonged; and growth may begin in the gamma field at a later date than in the control plots.
    c. Terminal growth may be reduced, but it may be difficult to measure the terminal growth of some desert shrub species.
    d. The number and size of leaves (and therefore the amount of chlorophyll) produced per bud per branch or per plant may be less in the gamma field than in the control plots.
    e. The number of new buds per plant at the end of the growing season may be less in the gamma field than in the control plots.
    f. The stems, leaves, and new buds produced by plants in the gamma field may be morphologically aberrant in comparison with those in the control plots.
2. Reduction of reproductive potential
    a. The time of flowering and time of pollination in the gamma field may be later than in the control plots.
    b. The number of flowers per plant or per dormant bud at the beginning of the growing season may be less in the gamma field than in the control plots.
    c. The frequency of pollen sterility and/or ovule abortion may be higher in the gamma field than in the control plots.
    d. The number of fruits per flower and/or the number of seeds per fruit may be less in the gamma field than in the control plots.
    e. The germination rate of seeds produced in the gamma field may be lower than that of seeds produced in the control plots.
    f. The mortality rate of seedlings grown from seed produced in the gamma field may be higher than that of seedlings grown from seed produced in the control plots.

It should be noted that none of the possible effects listed above are expected to be pronounced during the early part of the experiment. If the effects of chronic radiation on perennial plants are cumulative—and that appears to be the case in the Brookhaven National Laboratory forest (Woodwell, 1962)—some striking differences between vegetation in the gamma field and that of the control plots may become evident after several years of chronic exposure.

It should also be noted that any of the kinds of effects listed above could be caused by differences in environmental factors other than ionizing radiation. As mentioned earlier, the seasonal development (growth of leaves, development of flowers, onset of dormancy, etc.) of plants in Rock Valley and elsewhere at the Nevada Test Site appears to be closely regulated by the amount and seasonal distribution of rainfall. Summer and winter dormant periods may be related to rainfall and to seasonal temperature changes; and normal damage to buds may result from desiccation, from high or low temperature extremes, or from the activities of small mammals, insects or other organisms. We have reason to believe that ordinary environmental conditions and stresses in gamma field and control plots are essentially the same. The possibility that differences may exist, and that these may be large enough to cause differences in the behavior of plant populations, makes it necessary to measure certain environmental conditions in both the gamma field and in the control plots.

Tentative Procedure for Comparing the Gamma Field with Control Plots

A. Environmental Comparisons

1. United States Air Resources Laboratory: They have installed a standard weather station at the approximate center of the Rock Valley study area. Instruments at this station will provide data concerning air temperature and hu-

midity at 1.5 m above the surface, wind velocity and direction at 3 m above the surface, and precipitation.

2. Stations in Plots: Plans have also been made to install 6 to 12 supplementary stations in the gamma field and in each of the control plots. The instrumentation at each station will include: (a) "max-min" thermometer mounted under a sunshield about 37 cm above ground, (b) a rain gage consisting of a 17 cm plastic funnel mounted on a 2-liter bottle which will be buried in the ground and held in place by a lead washer, and (c) gypsum soil blocks and iron constantan thermocouples buried at depths of 0.15, 0.3, 0.6, 0.9, and 1.2 to 1.8 m below the surface.

Weekly records of air and soil temperature, rainfall, and soil moisture should provide fair estimates of the variations within plots and the differences between plots. If these conditions are essentially the same for all plots, it will probably be safe to assume that any major differences between the behavior of plant populations in the gamma field and that of similar populations in the control plots can be attributed to gamma radiation.

3. Dosimetry: While the dose rate in the gamma field is expected to be relatively uniform, variations due to topography and a certain amount of plant shielding are to be expected. Estimates of exposure doses to the various above-ground parts of plants in different parts of the gamma field can be obtained by attaching film badges and/or glass-rod dosimeters to selected plants. For comparative purposes, a smaller number of film badges and glass-rod dosimeters may be exposed in the control plots.

B. Comparison of Populations

1. Shrubs: A 15-m grid has been established in each of the four plots, and the intersections of grid-lines are marked by wooden stakes. Using each grid stake (a total of 400 per plot) as a sampling point, shrub populations will be sampled by the quarters method. At each point, the distance from the grid stake to the nearest plant in each quadrant of the grid will be measured to provide an estimate of the average interval between shrubs. The species, height, and average crown diameter of each selected shrub will also be recorded.

These data will provide a basis for estimating the actual and relative frequency, density, and dominance of each species. Estimates of dominance can be based on coverage or on the average volume of space occupied by each species.

Supplementary data may be collected by measuring the intercept distance of each species along the grid-line transects. Using all the grid lines in one direction, west to east or north to south, would provide a total transect distance of about 5670 m which is more than adequate. The line-intercept data, if deemed necessary, would provide additional estimates of coverage, point frequency, and relative density.

2. Herbs: At or near each grid stake we expect to establish a small (probably 2 × 5 dm) permanent quadrat for the sampling of herb populations. Since the number of herbaceous species in this area is four to five times greater than the number of shrub species, it may be necessary (at some later date) to increase the number of herb plots. Because most herbaceous species can be identified only when they are in flower, it may be necessary to tally each quadrat several times during a growing season. Once the species in each quadrat have been identified and counted, estimates of frequency and density can be made; and these data can be used to compare the herb populations in the gamma field with those in the control plots.

C. Comparison of Population Behavior

1. Shrubs: After the basic population parameters and relative importance of each species comprising the shrub vegetation of the gamma field have been established, we intend to select representative sets of 50 to 100 specimens from each of the major species' populations. If possible, these sets will be selected from among those plants included in the quarters-method survey. This procedure would greatly facilitate the relocation and identification of individual specimens.

The number of species observed and the number of specimens per species should be as large as possible, but practical considerations such as time and man power will set some upper limit. Statistical analyses of the initial data should provide estimates of the minimum numbers of observations required to reveal various magnitudes of differences between irradiated and non-irradiated plant populations. To facilitate the field work and the possible transfer of data to cards for computer analyses, separate records will be maintained for each specimen selected for careful observation.

The initial population sampling, the selection of specimens for periodic observation, and the initial collection of data should be completed before the end of winter dormancy. Subsequent observations and measurements will be made at various times during and after the growing season. The kinds of observations and measurements to be recorded for each specimen are indicated below.

a. Specimen identification code, e.g., Ld-D-NE-6682 would indicate Larrea divaricata in plot D located in the northeast quadrant of grid-point 6682.
b. Description of dormant plant:
  (1). Genus and species already recorded.
  (2). Height and average crown diameter already recorded.
  (3). Number of main branches at ground level, number of dead branches, and branches with apparently healthy dormant buds.
  (4). Each living branch should be numbered to facilitate the recording of
    (a). Length of branch from tip to lowest dormant bud.
    (b). Number and condition (H, U, or D to indicate healthy, uncertain, or dead) of buds per branch.
c. Development during spring-summer growing season
  (1). Number of buds per branch which remain dormant or die.
  (2). Number of buds per branch which produce leaves or flowers.
  (3). Number of flowers per branch, time of flowering and pollinations.
  (4). Number of leaves per foliage bud per branch and length of terminal growth.
  (5). Number of mature fruits per branch.
d. Late summer condition
  (1). Repeat tallies indicated by b(4) above
e. Development during summer-fall growing season
  (1). Repeat observations indicated by c (1-5) above.
f. Collection of samples for determination of
  (1). Weight and chlorophyll content of photosynthetic tissue produced per bud per branch and per plant.
  (2). Frequency of pollen sterility and/or ovule abortion.
  (3). Number of seeds per fruit, germination rate of seeds, and mortality rate of seedlings.
  (4). Nuclear volumes and chromosome numbers in dormant and

active meristems.

(N. B. In some cases, the samples required for the laboratory studies indicated above may be collected from the specimens selected for periodic observation; but to avoid the unnecessary disturbance of these particular plants, most such samples will be taken from other plants of the same species in the same vicinity.)

2. Herbs: As indicated earlier, there are several reasons for supposing that most herbaceous annuals are less sensitive than most woody perennials to damage by chronic radiation. Consequently, the study of low level radiation effects on herb populations may be delayed until satisfactory procedures for the study of shrub populations are well established.

The seedlings and rosettes of desert annuals are apparently cold-hardy and some investigators have expressed the opinion that virtually all the seedlings and rosettes one may observe in the fall will survive to flower the following spring. Winter exposure to chronic radiation might have some effect on the survival and flowering of these plants.

We plan this winter to mark the locations of seedlings and rosettes in a number of small quadrats in the gamma field and in an equal number of quadrats in one of the control plots. Those which survive the winter will be collected after the flowering season next spring. When time permits, these specimens will be identified and various measurements will be made to determine the relative success of irradiated and non-irradiated plants. By next year it may be possible to undertake a more sophisticated study in the field and to supplement field studies with laboratory studies.

The Need for Supplementary Studies and Additional Radiation Facilities

A. Limitations Imposed by the Experimental Design

As mentioned in the introduction, the Rock Valley experiment was designed primarily for the study of chronic, low level radiation effects on small mammal populations in their natural environments. The simultaneous study of plant populations in the same community should contribute to the animal study and to a broader understanding of low level radiation effects on a desert ecosystem.

The earlier sections of this report have given several reasons for the supposition that a chronic dose rate of only 4 R per day may cause some measurable changes in the photosynthetic and reproductive potentials of desert plants; but the actual effects on most of the plant populations in Rock Valley may be subtle and the interpretation of data indicating small differences may be confounded by slight differences in regard to other environmental factors. Unless the observed effects are greater than expected, it may be difficult to ascribe them entirely to radiation and not to any other environmental factor.

As a contribution toward the better understanding of desert plant ecology and the effects of low level radiation on desert ecosystems, even negative results might be of considerable value. As a contribution to the broader field of radiation ecology and the specialized field of radiation botany the value of this study would be greatly enhanced by supplementary experiments designed specifically to study the effects of gamma radiation on desert plant populations.

B. Cytological Studies Needed

The Brookhaven studies have shown: (1) that the frequency of chromosomal aberrations and somatic mutations in plants exposed to chronic radiation tend to increase with increasing dose rate, (2) that the chronic dose rate required to produce severe growth inhibition is virtually a linear function of nuclear and/or chromosome volume, and (3) that chronic dose rates required to produce severe growth inhibition are proportional to the chronic dose rates requried to produce greater or lesser effects.

It would be a worthwhile undertaking to determine whether these principles also apply to the effects of radiation on natural plant populations. Any competent cytologist could make the necessary determinations of nuclear volumes and chromosome numbers, and it might be possible to determine whether the frequency of chromosomal aberrations in the gamma field is higher than in the control plots. But, to determine the relative sensitivities and responses of different species populations in a natural plant community, the effects of several dose rates should be observed and measured. A point source such as the unshielded ^{137}Cs source being used at Brookhaven National Laboratory would be ideal for this purpose because it would provide a gradient of dose rates instead of the uniform, low dose rate required for the study of small mammal populations in Rock Valley.

C. Physiological-Ecology Studies Needed

Some of the experimental results described earlier have shown that other environmental factors are important in determining the responses of natural plant populations to chronic radiation. Certain aspects of the effects of gamma radiation on the tolerances of plants to other environmental factors could be studied in the laboratory and glasshouse, in a small radiation field such as the one on the campus of Emory University, or in an irradiated garden such as the one at Brookhaven National Laboratory. Those approaches offer many advantages, but the results may not be applicable to natural communities.

Before reaching broad conclusions concerning the ecological significance of results obtained from controlled-environment experiments, similar experiments should be performed in natural communities, and desert plant communities might be ideal for this purpose. For example, the interaction of radiation and moisture stress could be studied in Rock Valley by the comparison of plant populations on irrigated and non-irrigated plots exposed to different levels of chronic radiation.

D. Supplementary Field Studies Needed

While a great deal of useful data can be obtained from laboratory experiments, we are primarily interested in the potential effects of ionizing radiation on plant populations in their natural environments. Since natural environments are difficult (perhaps impossible) to duplicate in the laboratory, glasshouse, or experimental garden, there is an obvious advantage to be gained from conducting experiments in the field under natural or near-natural conditions except for the imposition of experimental treatments.

The field studies outlined earlier will provide information concerning the effects of one level (4 R per day) of chronic gamma radiation on one type of desert shrub community. In order to determine the potential range of radiation effects on desert plant communities or the maximum level of radiation which could be tolerated or even the lowest level which might be lethal to the least tolerant species, considerably more information will be required.

E. An Additional Radiation Source is Proposed

Estimates of the basic parameters concerning potential radiation effects on desert plant populations could be obtained most conveniently by means of an experiment similar to the forest irradiation experiment at Brookhaven National Laboratory (Woodwell, 1961-3; Woodwell et al., 1962-3). This would require the erection of another source in another part of Rock Valley. An unshielded source of 10,000 c of ^{137}Cs would expose a circular area of about 15 hectares, containing between 6000 and 7500 shrubs, to chronic radiation doses ranging from over 1000 R per day to slightly less than 1 R per day. The replication of most shrub and herb species at different dose rates should be sufficient to provide good estimates of the major parameters relating to the relative sensitivities of different species to chronic radiation in their natural environments. After 2 or 3 years in Rock Valley, the source could be moved into another community type, and similar estimates would be obtained for a different array of species. If the source were designed to make it portable or semi-portable, a greater variety of field experiments could be undertaken.

Summary

1. The primary objective of the Rock Valley experiment is to study the effects of chronic, low level (4 R per day) gamma radiation on the small mammal populations in a 9-hectare enclosure. This paper describes the plans which have been made to compare the behavior of plant populations in the gamma field with that of similar populations in non-irradiated control plots.

2. Preliminary studies have indicated that the soils and the shrub populations of the gamma field are sufficiently similar to those of the control plots that valid comparisons can be made between them.

3. Previous studies at the Nevada Test Site have provided no unequivocal evidence of radiation damage to plant populations exposed to the prompt and residual effects of nuclear detonations in Yucca Flat; but experimental studies at Brookhaven National Laboratory and Emory University have provided data and established principles which can be used, within broad uncertain limits, to predict the possible effects of chronic (4 R per day) gamma radiation on the plant populations of Rock Valley.

4. Thus far, our plans to study radiation effects on plants in Rock Valley have been based on the expectation that a chronic gamma dose rate of 4 R per day will be high enough to damage the nuclei of meristematic cells in the dormant buds of the most sensitive shrub species. We expect the results of this damage to be measured as a reduction of growth, photosynthetic potential and/or reproductive potential.

5. Tentative procedures have been outlined for the measurement of environmental factors and population parameters in the gamma field and control plots. Procedures have also been outlined for the periodic collection of data which should permit us to compare the behavior (seasonal development, growth of photosynthetic tissues, and reproductive success) of plant populations in the gamma field with that of similar populations in one or more control plots.

6. The limitations of this particular study and the need for supplementary studies are also considered. The value of plant studies already planned for Rock Valley could be greatly enhanced and the scope of radiation botany studies at the Nevada Test Site could be greatly expanded by the installation of an unshielded gamma source (similar to the ^{137}Cs source now in use at Brookhaven National Laboratory) in another part of Rock Valley.

This report is included for its historical value to the Rock Valley study.

REFERENCES

Aldous, A. E., and H. L. Shantz 1924 Types of vegetation in the semi-arid portion of the United States and their economic significance. Jour. Agr. Res. 28:99-127.

Allen, E. K., and O. N. Allen 1965 Non-leguminous plant symbiosis, p. 77-106. In C. M. Gilmore, and O. N. Allen (eds.) Microbiology and Soil Fertility. Oregon State Univ. Press, Corvallis.

Allen, M. B. 1963 Evaluation of the carbon-14 technique for measurement of primary production, p. 477-480. In V. Schultz and A. W. Klement, Jr. (eds.) Radioecology. Reinhold Publ. Corp., New York.

Allred, D. M. 1963 Mites from pocket mice at the Nevada Test Site. Entomol. Soc. Wash., Proc. 65:231-233.

Allred, D. M. 1963 Mites on grasshopper mice at the Nevada atomic test site. Great Basin Natur. 22:101-104.

Allred, D. M. 1963 Mites on squirrels at the Nevada atomic test site. Jour. Parasitol. 48:817.

Allred, D. M. 1965 Note of phalangids at the Nevada Test Site. Great Basin Natur. 25:37-38.

Allred, D. M., and D. E. Beck 1962 Ecological distribution of mites on lizards at the Nevada atomic test site. Herpetologica 18:47-51.

Allred, D. M., and D. E. Beck 1963 Comparative ecological studies of animals at the Nevada Test Site, p. 327-331. In V. Schultz and A. W. Klement, Jr., Radioecology. Reinhold Publ. Corp. New York.

Allred D. M., and D. E. Beck 1963 Ecological distribution of some rodents at the Nevada atomic test site. Ecology 44:211-214.

Allred, D. M., and D. E. Beck 1963 Range of movement and dispersal of some rodents of the Nevada atomic test site. Jour. Mammal. 44:190-200.

Allred, D. M., and D. E. Beck 1964 Arthropod associates of plants at the Nevada Test Site. Brigham Young Unv. Sci. Bull. vol. 5 no. 2, 16 p.

Allred, D. M., and D. E. Beck 1964 Mites on reptiles at the Nevada nuclear test site. Amer. Micro. Soc., Trans. 83:266-268.

Allred, D. M., D. E. Beck, and C. D. Jorgensen 1963 Biotic communities of the Nevada Test Site. Brigham Young Univ. Sci. Bull., vol. 2 no. 2, 52 p.

Allred, D. M., D. E. Beck, and C. D. Jorgensen 1963 Close-in effects of an underground nuclear detonation on small mammals and selected invertebrates (Project Sedan). USAEC Report PNE-226F, 18 p.

Allred, D. M., D. E. Beck, and C. D. Jorgensen 1963 Nevada Test Site study areas and specimen depositories. Brigham Young Univ. Sci. Bull., vol. 2 no. 4, 15 p.

Allred, D. M., D. E. Beck, and C. D. Jorgensen 1966 A summary of the ecological effects of nuclear testing on native animals at the Nevada Test Site. Utah Acad. Sci., Arts, and Letters, Proc. 43:252-260.

Allred, D. M., D. E. Beck, and J. R. Murdock 1960 Comparative ecological studies of animals exposed to nuclear detonation. Ibid. 37:152-153.

Allred, D. M., and M. A. Goates 1964 Mites from mammals at the Nevada nuclear test site. Great Basin Natur. 24:71-73.

Allred, D. M., and M. A. Goates 1964 Mites from wood rats at the Nevada Test Site. Jour.Parasitol. 50:171.

Allred, D. M., and D. E. Johnson, and D. E. Beck 1965 A list of some bee flies of the Nevada Test Site. Great Basin Natur. 25:5-11.

Allred, D. M., and S. Mulaik 1965 Two isopods of the Nevada Test Site.

Great Basin Natur. 25:43-47.

al-Rabbat, M. F. 1962 The effect of moisture, depth of planting, and compaction of seedling emergence on winterfat and crested wheatgrass. Master's Thesis, Univ. of Arizona (Tucson) 54 p.

Amen, R. D. 1963 The concept of seed dormancy. Amer. Sci. 51:408-423.

Anderson, D. J. 1970 Analysis of pattern in Atriplex vesicaria communities from the Riverine Plain of New South Wales, p. 63-68. In R. Jones (ed.) Studies of the Australian Arid Zone—The Biology of Atriplex. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ., Canberra, Australia.

Ashby, E. 1932 Transpiratory organs of Larrea tridentata, and their ecological significance. Ecology 13:182-188.

Attiwill, P. M. 1968 The loss of elements from decomposing litter. Ecology 49:142-145.

Ault, W. U., R. G. Senechal, and W. E. Erlebach 1970 Isotopic composition as a natural tracer of lead in the environment. Environ. Sci. and Technol. 4:305-313.

Baashear, M. M., and N. E. West 1968 Determination of adequate plot size by use of mean distance between salt desert shrubs. Southwest Natur. 13:61-74.

Baetcke, K. P., A. H. Sparrow, C. H. Nauman, and Susan S. Schwemmer 1967 The relationship of DNA content to nuclear and chromosome volumes and to radiosensitivity (LD_{50}). Nat. Acad. Sci. (U.S.), Proc. 58: 533-540.

Bagnold, R. A. 1954 The physical aspects of dry desert. In Cloulsley-Thompson and Chadwich (eds.) Biology of Deserts. Inst. of Biol., London.

Barber, S. A., J. M. Walker, and E. H. Vasey 1963 Mechanisms on the movement of plant nutrients from the soil and fertilizer to the plant root. Jour. Agr. Food Chem. 11:204-207.

Barbour, M. G. 1968 Germination requirements of the desert shrub Larrea divaricata. Ecology 49:915-923.

Barbour, M. G. 1969 Age and space distribution of the desert shrub Larrea divaricata. Ecology 50:679-685.

Barbour, M. G. 1969 Patterns of genetic similarity between Larrea divaricata of North and South America. Amer. Midland Natur. 81:54-67.

Barker, Susan, and R. T. Lange 1970 Population ecology of Atriplex under sheep stocking, p. 105-120. In R. Jones (ed.) Studies of the Australian Arid Zone—The Biology of Atriplex. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ., Canberra, Australia.

Bartholomew, Bruce 1970 Bare zone between California shrub and grassland communities: The role of animals. Sci. 170:1210-1212.

Baurmash, L., J. W. Neel, W. K. Vance, H. M. Mork, and K. H. Larson 1958 Distribution and characterization of fallout and airborne activity from 10 to 60 miles from ground zero (Operation Teapot). USAEC Report WT-1178.

Beals, E. W. 1968 Spatial pattern of shrubs on a desert plain in Ethiopia. Ecology 49:744-746.

Beals, E. W. 1969 Vegetational change along altitudinal gradients (studies in Ethiopia show that discreteness of zonation varies with steepness of slope). Science 165:981-985.

Beard, J. S. 1969 The vegetation survey of western Australia. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 10.

Beatley, Janice C. 1962 Vascular plants of the U.S. Atomic Energy Commission's Nevada Test Site, Nye County, Nevada. USAEC Report UCLA-12-508. 33 p.

Beatley, Janice C. 1963 Annual vegetation of the northern Mojave Desert. Ecol. Soc. Amer., Bull. (abstr.) 44:122-123.

Beatley, Janice C. 1963 Vegetation and environments of the Nevada Test Site. Ibid. 44:123.

Beatley, Janice C. 1964 Ecological status of introduced species at the Nevada Test Site. Ibid. 45:78.

Beatley, Janice C. 1964 Effects on desert vegetation of a nuclear detonation, Nevada Test Site. Ibid. 45:80.

Beatley, Janice C. 1964 The vascular flora of the Nevada Test Site, Nye County, Nevada. Amer. Jour. Bot. (abstr.) 51:687.

Beatley, Janice C. 1965 Ecology of the Nevada Test Site. I. Geographic and ecologic distributions of the vascular flora (annotated check list). USAEC Report UCLA 12-553. 69 p.

Beatley, Janice C. 1965 Ecology of the Nevada Test Site. II. Status of introduced species. USAEC Report UCLA 12-554. 39 p.

Beatley, Janice C. 1965 Ecology of the Nevada Test Site. III. Survival of winter annuals, 1963-64. USAEC Report UCLA 12-555. 21 p.

Beatley, Janice C. 1965 Ecology of the Nevada Test Site. IV. Effects of the Sedan detonation on desert shrub vegetation in northeastern Yucca Flat, 1962-65. USAEC Report UCLA 12-571. 55 p.

Beatley, Janice C. 1965 Effects of radioactive and non-radioactive dust upon *Larrea divaricata* Cav., Nevada Test Site. Health Phys. 11:1621-1625.

Beatley, Janice C. 1965 Survival of winter annuals in the northern Mojave Desert. Ecol. Soc. Amer., Bull. (abstr.) 46:40.

Beatley, Janice C. 1966 Ecological status of introduced Brome grasses (*Bromus* spp.) in desert vegetation of southern Nevada. Ecology 47:548-554.

Beatley, Janice C. 1966 *Mirabilis pudica* populations in southern Nye County, Nevada. Leafl. Western Bot. X:294-296.

Beatley, Janice C. 1966 The vascular flora of the Nevada Test Site, Nye County, Nevada. Amer. Jour. Bot. (abstr.) 51:687.

Beatley, Janice C. 1966 Winter annual vegetation following a nuclear detonation in the northern Mojave Desert (Nevada Test Site). Radiat. Bot. 6:69-82.

Beatley, Janice C. 1967 Survival of winter annuals in the northern Mojave Desert (at Nevada Test Site). Ecology 48:745-750.

Beatley, Janice C. 1969 Biomass of desert winter annual plant populations in southern Nevada. Oikos 20:261-273.

Beatley, Janice C. 1969 Dependence of desert rodents on winter annuals and precipitation. Ecology 50:721-724.

Beatley, Janice C. 1969 Vascular plants of the Nevada Test Site, Nellis Air Force Range, and Ash Meadows (northern Mojave and southern Great Basin Deserts, south-central Nevada). USAEC Report UCLA 12-705. 122 p.

Beatley, Janice C. 1971 Ecologic and geographic distribution of the vascular plants of southern Nye County, and adjacent parts of Clark, Lincoln, and Esmeralda Counties, Nevada. USAEC Report UCLA 12-800 (Suppl. to UCLA 12-705).

Beck, D. E., D. M. Allred, J. R. Murdock, C. D. Jorgensen, C. L. Hayward, and W. W. Tanner. 1964 Nevada Test Site desert ecology. Utah Acad. Sci., Arts, and Letters, Proc. 41:202-210.

Becker, D. A. 1969 Stem abscission in the tumbleweed, *Kochia*. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 11.

Becking, J. H. 1970 Plant-endophyte symbiosis in non-leguminous plants.

Plant and Soil. 32:611-654.

Beetle, A. A. 1960 A study of sagebrush. Wyoming Expt. Sta. Bull. #368, 83 p.

Benedict, H. M. 1941 The inhibitory effect of dead roots on the growth of brome grass. Jour. Amer. Soc. Agron. 33:1108-1109.

Benson, L. 1950 The Cacti of Arizona. (2nd ed.) Univ. New Mexico Press, Albuquerque. 135 p.

Benson, L., and R. A. Darrow 1945 A manual of southwestern desert trees and shrubs. Univ. Ariz. Biol. Sci., Bull. no. 6. 411 p.

Benson, L., and R. A. Darrow 1954 The Trees and Shrubs of the Southwestern Deserts. Univ. of Ariz. Press, Tucson and Univ. of New Mexico Press, Albuquerque. 437 p.

Billings, W. D. 1945 The plant associations of Carson Desert region western Nevada. Butler Univ. Bot. Studies 7:89-128.

Billings, W. D. 1949 The shadscale vegetation zone of Nevada and eastern California in relation to climate and soils. Amer. Midland Natur. 42:87-109.

Billings, W. D. 1950 Vegetation and plant growth as affected by chemically altered rocks in the western Great Basin. Ecology 31:62-74.

Billings, W. D. 1952 The environmental complex in relation to plant growth and distribution. Quart. Rev. Bot. 27:251-265.

Bjorkman, O., and E. Gauhl 1969 Carboxydismutase activity in plants with and without β-carboxylation photosynthesis. Planta 88:197-203.

Black, C. C., T. M. Chen, and R. H. Brown 1969 Biochemical basis for plant competition. Weed Sci. 17:338-344.

Blaisdell, J. P. 1953 Ecological effects of planned burning of sagebrush-grass range on the upper Snake River plains. USDA Tech. Bull. no. 1075.

Blankenship, J. O., and D. R. Smith 1967 Breaking seed dormancy in Parry's clover by acid treatment. Jour. Range Manage. 20:50.

Blaylock, B. G. 1967 Effects of ionizing radiation on interspecific competition. 2nd Nat. Symp. Radioecol. Proc. (Ann Arbor, Mich.) May 15 - 17, p. 61-67.

Blummer, J. C. 1910 A comparison between two mountain sides. Plant World 13:134-140.

Blummer, J. C. 1911 Change of aspect with altitude. Plant World 14:236-248.

Blydenstein, J., C. R. Hungerford, G. I. Day, and R. R. Humphrey 1957 Effect of domestic livestock exclusion on vegetation in the Sonoran Desert. Ecology 38:522-526.

Bogusch, E. R. 1952 Brush invasion in the Rio Grande plain of Texas. Tex. Jour. Sci. 4:85-91.

Bond, G. 1963 The root nodules of non-leguminous angiosperms, p. 72-91. In P. S. Nutman and B. Morse (eds.) Symbiotic Associations. Cambridge Univ. Press. London.

Bond, G. 1967 Fixation of nitrogen by higher plants other than legumes. Annu. Rev. Plant Physiol. 18:107-126.

Bonner, J. 1950 The role of toxic substances in the interactions of higher plants. Bot. Rev. 16:51-65.

Bowen, H. J. H., and D. Gibbons 1963 Radioactivation Analysis. Oxford Univ. Press.

Bradley, W. G., and J. E. Deacon 1965 The biotic communities of southern Nevada. Univ. Nev., Des. Res. Inst., no. 9 Preprint Ser. 86 p.

Branscomb, B. L. 1958 Shrub invasion of a southern New Mexico desert grassland range. Jour. Range Manage. 11:129-133.

Branson, F. A., R. F. Miller, and I. S. McQueen 1967 Geographic distribution and factors affecting the distribution of salt desert shrubs in the United States. Ibid. 20:287-296.

Branson, F. A., R. F. Miller, and I. S. McQueen 1970 Plant communities and associated soil and water factors on shale-derived soils in northeastern Montana. Ecology 51:391-407.

Bray, W. L. 1898 On the relation of the flora of the lower Sonoran zone in North America to the flora of the arid zones of Chile and Argentina. Bot. Gaz. 26:121-147.

Bray, W. L. 1901 The ecological relations of the vegetation of western Texas. Ibid. 32:99-123, 195-217, 262-291.

Breazeale, J. F., and F. J. Crider 1934 Plant association and survival, and the buildup of moisture in semi-arid soils. Ariz. Agr. Exp. Sta. Tech. Bull. 53:95-123.

Bremner, J. M. 1968 Nitrogenous constituents of soil organic matter and their role in soil fertility. Study Week Org. Matter Soil Fert. 1968,143-193. (North-Holland Publ. Co., Amsterdam, Neth.)

Broadbent, F. E. 1968 Turnover of nitrogen in soil organic matter. Ibid. 1968, 61-88.

Brock, T. D. 1967 The ecosystem and the steady state. BioScience 17: 166-169.

Brownell, P. F. 1965 Sodium as an essential micronutrient element for a higher plant (*Atriplex vesicaria*). Plant Physiol. 40:460-468.

Brownell, P. F. 1968 Sodium as an essential micronutrient element for some higher plants. Plant and Soil 28:161-164.

Brun, J. W., and T. W. Box 1963 A comparison of line intercepts and random point frames for sampling desert shrub vegetation. Jour. Range Manage. 16:21-25.

Brunner, J. R. 1969 Identification of sagebrush (*Artemisia*) through thin-layer chromatography. Int. Conf. on Arid Lands in a Changing World (Tucson) June 3 - 13.

Buchanan, B. A. 1968 Allelopathic reactions of bur buttercup tissue leachates in vitro and in vivo. Ecol. Soc. Amer., Bull. (abstr.) 49:70-71.

Buechner, H. K. 1944 The range vegetation of Kerr County, Texas, in relation to livestock and white-tailed deer. Amer. Midland Natur. 31:698-743.

Buffington, L. C., and C. H. Herbel 1965 Vegetational changes on a semidesert grassland range from 1858 to 1963. Ecol. Monogr. 35:139-164.

Cabrera, A. L. 1955 Latin America. *In* Arid Zone Research—VI. Plant Ecology. Reviews of Research. UNESCO, Paris. p. 77-113.

Cain, S. A., and G. M. Castro 1959 Manual of Vegetation Analysis. Harper, New York.

Cameron, S. H., A. Wallace, and R. T. Mueller 1954 Seasonal changes in dry matter and nutrient composition of bearing Valencia orange trees. Proc. Amer. Soc. Hort. Sci. 63:59-66.

Campbell, R. S., and J. G. Keller 1932 Growth and reproduction of *Yucca elata*. Ecology 13:364-374.

Canfield, R. 1941 Application of the line interception method of sampling range vegetation. Jour. Forest. 39:288-294.

Cannon, Helen L. 1960 Botanical prospecting for ore deposits. Science 132:591-598.

Cannon, H. L. and J. M. Bowles 1962 Contamination of vegetation by tetraethyl lead. Ibid. 137:765-766.

Cannon, W. A. 1905 On the water-conducting systems of some desert plants. Bot. Gaz. 39:397-408.

Cannon, W. A. 1908 The topography of the chlorophyll apparatus in desert plants. Carnegie Inst. Wash.

Cannon, W. A. 1911 The root habits of desert plants. Ibid. Publ. 131. 96 p.

Chaminade, R. 1968 Specific effect of organic matter on plant nutrition and yield. Study Week Org. Matter Soil Fert. 777-804 (French). North-Holland Publ. Co. Amsterdam, Neth.

Chapman, H. D., and P. F. Pratt 1961 Methods of analysis for soils, plants, and waters. Div. Agr. Sci., Univ. of Calif., Riverside.

Chapman, V. J. 1960 Salt Marshes and Salt Deserts of the World. Interscience Publ. New York. 302 p.

Chase, Valerie C., and B. R. Strain 1966 Propagation of some woody desert perennials by stem cuttings. Madroño 18:240-243.

Chatterton, N. J., and C. M. McKell 1969 *Atriplex polycarpa*: I. Germination and growth as affected by sodium chloride in water cultures. Agron. Jour. 61:448-450.

Chatterton, N. J., and C. M. McKell 1969 Time of collection and storage in relation to germination of desert saltbush seed. Jour. Range Manage. 22:355-356.

Chatterton, N. J., C. M. McKell, F. T. Bingham, and W. J. Clawson 1970 Absorption of Na, Cl, and B by desert saltbush in relation to composition of nutrient solution culture. Agron. Jour. 62:351-352.

Chatterton, N. J., C. M. McKell, J. R. Goodin, and F. T. Bingham 1969 *Atriplex polycarpa*: II. Germination and growth in water cultures containing high levels of boron. Ibid. 61:451-453.

Chew, R. M., and Alice E. Chew 1965 The primary productivity of a desert shrub (*Larrea tridentata*) community. Ecol. Monogr. 35:355-375.

Chow, T. J. 1970 Lead accumulation in roadside soil and grass. Nature 225:295-296.

Clarke, L. D., and N. E. West 1969 Germination of *Kochia americana* in relation to salinity. Jour. Range Manage. 22:286-287.

Clements, F. E. 1920 Plant Indicators. Carnegie Inst., Wash. Publ. no. 353. 388 p.

Cook, C. W., and R. Hurst 1962 A quantitative measure of plant association in ranges in good and poor condition. Jour. Range Manage. 15:266-273.

Cook, C. W., L. A. Stoddart, and L. E. Harris 1959 The chemical content in various portions of the current growth of salt desert shrubs and grasses during winter. Ecology 40:644-650.

Cook, O. F. 1908 Change of vegetation on the south Texas prairies. USDA Bur. Plant Ind., Circ. no. 14.

Copple, R. F., and C. P. Pase 1967 A vegetative key to some common Arizona range grasses. U.S. Forest Serv. Res. Paper RM-27. 72 p.

Cottam, G., and J. T. Curtis 1956 The use of distance measures in phytosociological sampling. Ecology 37:451-460.

Cottam, W. P. 1937 Has Utah lost claim to the lower Sonoron zone? Science 85:563-564.

Coville, F. V. 1893 Botany of the Death Valley expedition. U.S. Nat. Herb. Contr. no. 4. 363 p.

Cowan, J. J., and R. B. Platt 1963 Radiation dosages in the vicinity of an unshielded reactor. p. 311-318. *In* V. Schultz and A. W. Klement (eds.) Radioecology. Reinhold Publ. Corp. New York.

Coxworth, E. C. M., J. M. Bell, and R. Ashford 1969 Preliminary evaluation of Russian thistle, *Kochia*, and garden *Atriplex* as potential high protein content seed crops for semiarid areas. Can. Jour. Plant Sci. 49:427-434.

Cozic-Trichet, Jeanne, and Marie Goas 1969 Taxonomic study of *Atriplex* species. Amino acids and free amides. C. R. Acad. Sci., Paris, Ser. D, 268:1034-1037.

Crawford, A. C. 1908 Notes, mainly bibliographical, on two American plants–sleepygrass and creosotebush. Pharm. Rev. 26:230-235.

Crossley, D. A., Jr. 1967 Comparative movement of ^{106}Ru, ^{60}Co, and ^{137}Cs in arthropod food chains. p. 687-695. *In* 2nd Nat. Symp. Radioecol., Proc. (Ann Arbor, Mich.) May 15 - 17.

Croxton, F. E. 1959 Elementary Statistics with Applications in Medicine and the Biological Sciences. Dover Publ., Inc. New York.

Cunningham, G. L., and B. R. Strain 1969 An ecological significance of seasonal leaf variability in a desert shrub. Ecology 50:400-408.

Cunningham, G. L., and B. R. Strain 1969 Irradiance and productivity in a desert shrub. Photosynthetic 3:69-71.

Dahlman, R. C. 1968 Tagging native grassland vegetation with carbon-14. Ecology 49:1199-1203.

Dahlman, R. C., S. I. Auerbach, and P. B. Dunway 1969 Behavior of cesium-137 tagged particles in fescue meadow. Environ. Contam. Radioactive Matter., Proc. Semin. p. 153-165.

Dalton, P. D., Jr. 1962 Ecology of the creosotebush *Larrea tridentata* (DC) Cov. Ph. D. Thesis, Univ. Ariz. (Tucson) 170 p. Univ. Microfilms, Ann Arbor, Mich. (Diss. abstr. 62-21).

Daniel, C. P. 1963 A study of succession in fields irradiated with fast neutron and gamma radiation. p. 277-283. *In* V. Schultz and A. W. Klement (eds.) Radioecology. Reinhold Publ. Corp. New York.

Darrow, R. A. 1935 A study of the transpiration rates of several desert grasses and shrubs as related to environmental conditions and stomatal periodicity. Master's Thesis, Univ. Ariz. (Tucson). 114 p.

Darrow, R. A. 1944 Arizona range resources and their utilization. I. Cochise County. Ariz. Agr. Exp. Sta. Tech. Bull. no. 103 p. 311-366.

Davis, J. D. 1968 Effect of sagebrush distillate on the germination of cheatgrass seed. USAEC Annu. Report (1967) BNWL-714 1:8.23.

Davis, J. J. 1963 Cesium and its relationships to potassium in ecology. p. 539-556. *In* V. Schultz and A. W. Klement, Jr. (eds.) Radioecology. Reinhold Publ. Corp. New York.

Deacon, J. E., et al. 1967 Studies on the ecology of Saratoga Springs, Death Valley National Monument. Final report of research accomplished under Contract 14-10-0434-1989, National Park Service.

Del Moral, R., and C. H. Muller 1970 Allelopathic effects of *Eucalyptus camaldulensis*. Amer. Midland Natur. 83:254-282.

Delwiche, C. C. 1964 The cycling of carbon and nitrogen in the biosphere. Microbiol. Soil Fert., Proc. Biol. Colloquium, Oregon State Univ. Press p. 29-58.

Desai, M. C. 1937 Effect of certain nutrient deficiencies on stomatal behavior. Plant Physiol. 12:253-283.

Dhar, N. R. 1968 Value of organic matter, phosphates, and sunlight in nitrogen fixation and fertility improvement in world soils. Study Week Org. Matter Soil Fert. p. 243-360. North-Holland Publ. Co., Amsterdam, Neth.

Dilworth, M. J. 1966 Acetylene reduction by nitrogen-fixing preparations from *Clostridium pasteurianum*. Biochim. Biophys. Acta 127:285-294.

Dittmer, H. J. 1959 Study of the root system of certain sand dune plants in New Mexico. Ecology 40:265-273.

Dittmer, H. J. 1964 Certain characteristics of the roots of desert plants. Amer. Jour. Bot. 51:673.

Dodd, J. D., and G. L. Van Amburg 1970 Distribution of Cs^{134} in *Andro-*

pogon scoparius Michx. clones in two native habitats. Ecology 51:683-689.

Donini, B., A. H. Sparrow, L. A. Schairer, and R. C. Sparrow 1967 The relative biological efficiency of gamma rays and fission neutrons in plant species with different nuclear and chromosome volumes. Radiat. Res. 32:692-705.

Drake, B. G., and F. B. Salisbury 1970 Leaf temperatures in a variety of natural environments. Ecol. Soc. Amer., Bull. (abstr.) 51:26.

Duisberg, P. C. 1951 Economic potentials of the creosotebush. Chemurgic Dig. 10:6-8.

Duisberg, P. C. 1952 Desert plant utilization. Texas Jour. Sci. 4:269-283.

Duisberg, P. C. 1952 Development of a feed from the creosotebush and the determination of its nutritional value. Jour. Animal Sci. 11:175-180.

Duisberg, P. C. 1952 Some relationships between xerophytism and the content of resin, nordihydroguaiaretic acid, and protein of Larrea divaricata Cav. Plant Physiol. 27:769-777.

Dunbier, R. 1968 The Sonoran Desert, its Geography, Economy, and People. Univ. Ariz. Press, Tucson, Ariz. 426 p.

Eckert, R. E., Jr. 1954 A study of competition between whitesage and halogeton in Nevada. Jour. Range Manage. 7:223-225.

Eckert, R. E., and F. E. Kinsinger 1958 The effect of Halogeton glomeratus leachate on soil and vegetation. 1948 progress report of range management. Nev. Agr. Exp. Sta. Circ. 22:15-16.

Egle, K., and H. Fock 1969 Relation between photorespiration and photosynthesis. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p.52.

Ehrler, W. L. 1963 Water absorption of alfalfa as affected by low root temperatures. Agron. Jour. 55:363-366.

Ellern, S. J., and N. H. Tadmore 1966 Germination of range plant seeds at fixed temperatures. Jour. Range Manage. 19:341-345.

Ellern, S. J., and N. H. Tadmore 1967 Germination of range plant seeds at alternating temperatures. Ibid. 20:72-77.

Essington, E. H., H. Nishita, and A. Steen 1965 Release and movement of radionuclides in soils contaminated with throwout material from an underground thermonuclear detonation. Health Physics 11:689-698.

Essington, E., H. Nishita, and A. Wallace 1962 Influence of chelates on availability of fission products to plants grown in a contaminated soil. Soil Sci. 94:96-105.

Evans, H. J., and A. H. Sparrow 1961 Nuclear factors affecting radiosensitivity: II. Dependence on nuclear and chromosomal structure and organization. Brookhaven Symposia on Biol. 14:100-127.

Evenari, M. 1952 The water balance of plants in desert conditions. Res. Coun. Israel, Spec. Publ. 2:266-274.

Evenari, M., and Y. Gutterman 1966 The photoperiodic response of some desert plants. Z. Pflanzenphysiol. Z. Bot. 54:7-27.

Evenari, M., and R. Ritcher 1937 Physiological-ecological investigations in the wilderness of Judea. Jour. Linn. Soc. Bot. 51:333-381.

Everett, P. C. 1957 A summary of the culture of California plants at the Rancho Santa Ana Botanic Garden, 1927-1950. Pub. by The Rancho Santa Ana Botanic Garden, Claremont, California.

Fahn, A. 1955 Xylem structure and annual rhythm of development in trees and shrubs of the desert. I. Tamarix aphylla, T. jordanis var. negevensis, T. gallica var. moris-ortui. Trop. Woods 109:81-94.

Fahn, A. 1963 Xylem structure and annual rhythm of development in trees and shrubs of the desert. IV. Shrubs. Res. Coun. Israel, Bull., Sect. D Bot. 11:198-209.

Fahn, A. 1964 Some anatomical adaptations of desert plants. Phytomorphology 14:93-102.

Farnsworth, R. B., and M. W. Hammond 1968 Root nodules and isolation of endophyte on Artemisia ludoviciana. Utah Acad. Sci., Arts, and Letters, Proc. 45:182-188.

Fautin, R. W. 1946 Biotic communities of the northern desert shrub biome in western Utah. Ecol. Monogr. 16:251-310.

Ferguson, C. W. 1950 An ecological analysis of lower Sonoran zone relic vegetation in south-central Arizona. Master's Thesis, Univ. Arizona. (Tucson) 41 p.

Ferguson, C. W. 1960 Annual rings in big sagebrush, Artemisia tridentata. Ph. D. Thesis, Univ. Arizona (Tucson).

Ferguson, C. W. 1964 Annual rings in big sagebrush. Lab. Tree-Ring Res., Paper no. 9, Univ. Ariz. Press, Tucson. 95 p.

Fireman, M., and H. E. Hayward 1952 Indicator significance of some shrubs in the Escalante Desert, Utah. Bot. Gaz. 114:143-155.

Flowers, S. 1934 Vegetation of the Great Salt Lake region. Ibid. 95:353-418.

Fosberg, F. R. 1938 The lower Sonoran zone in Utah. Science 87:39-40.

Fosberg, F. R. 1940 The aestival flora of the Mesilla Valley Region, New Mexico. Amer. Midland Natur. 23:573-593.

Frank, E. C., and R. Lee 1966 Potential solar beam irradiation on slopes: Tables for 30° to 50° latitude. U.S. Forest Serv. Res. Paper RM-18, 116 p.

Fredriksson, L., H. Lonsjo, and A. Eriksson 1969 Studies on plant accumulation of fission products under Swedish conditions. XII. Uptake of ^{137}Cs by barley and peas from 12 different top soils combined with 2 subsoils in a long-term micro plot experiment. FAO 4 Rapport, C 4405-28, The Res. Inst. Nat. Defence, Stockholm, Sweden.

French, N. R. 1963 Fallout and natural populations. First Int. Conf. Wildlife Disease, Proc. (High View, N.Y.) June 24 - 27, 1962. p. 152-156.

French, N. R. 1963 Review and discussion of barium. p. 557-560. In V. Schultz and A. W. Klement, Jr. (eds.) Radioecology. Reinhold Publ. Corp. New York.

French, N. R. 1963 The source of ingested radioactivity in desert rodents. Ecol. Soc. Amer., Bull. (abstr.) 44:74.

French, N. R. 1964 A radiation facility for ecological studies at the AEC Nevada Test Site. Ibid. 45:79.

French, N. R. 1964 Analysis of dispersal in desert rodents. Ibid. 45:115.

French, N. R. 1964 Description of a study of ecological effects on a desert area from chronic exposure to low level ionizing radiation. USAEC Report UCLA 12-532. 27 p.

French, N. R. 1965 Mortality and fertility in a desert population of pocket mice. Ecol. Soc. Amer., Bull. (abstr.) 46:122.

French, N. R. 1965 Radiation and animal populations: problems, progress and projections. Health Physics 11:1557-1568.

French, N. R. 1966 Irradiated desert rodent populations. In G. A. Sacher (ed.) Radiation Effects on Natural Populations. Div. of Biol. Med. Res., Argonne Nat. Lab., Lemont, Ill. p. 22.

French, N. R. 1969 Effects of irradiation of a desert ecosystem for five years. Int. Symp. Radioecol., Proc. (Cadarache, France) Sept. p. 1151-1165.

French, N. R. 1969 Radiation sensitivity of rodent species. Nature 222: 1003-1004.

French, N. R., and K. H. Larson 1963 Environmental pathways of radioactive iodine from nuclear test in arid regions. p. 77-81. In V. Schultz and A. W. Klement, Jr. (eds.) Radioecology. Reinhold Publ. Corp. New York.

French, N. R., B. G. Maza, and A. P. Aschwanden 1965 Duration of life in confined populations of desert rodents. Ecol. Soc. Amer., Bull. (abstr.) 46:40.

French, N. R., B. G. Maza, and A. P. Aschwanden 1966 Periodicity of desert rodent activity. Science 154:1194-1195.

French, N. R., B. G. Maza, and A. P. Aschwanden 1967 Life spans of Dipodomys and Perognathus in the Mojave Desert. Jour. Mammal. 48: 537-548.

Fuller, W. H., R. E. Cameron, and R. J. Nicholas 1960 Fixation of nitrogen in desert soils by algae. 7th Int. Congr. Soil Sci., Trans. 2:617-623.

Funke, G. L. 1943 The influence of Artemisia absinthium on neighboring plants. Blumea 5:281-296.

Garcia, E., C. Soto, and F. Miranda 1960 Larrea y clima. Univ. Nacional de Mexico, Instituto de Biologia, Anales 31:133-171.

Garcia, P. L. 1960 The influence of Larrea divaricata and Atriplex canescens on soil pH, electrical conductivity and soluble sodium content. Master's Thesis, New Mexico Highlands Univ. (Las Vegas, N. M.). 63 p.

Garcia-Moya, E., and C. M. McKell 1970 Contribution of shrubs to the nitrogen economy of a desert-wash plant community. Ecology 51:81-88.

Gardner, J. L. 1951 Vegetation of the creosote bush area of the RioGrande Valley in New Mexico. Ecol. Monogr. 21:379-403.

Garrett, A. 1967 Compositional changes of ecosystems during chronic gamma irradiation. 2nd Nat. Symp. Radioecol., Proc. (Ann Arbor, Mich.) May 15 - 17. p. 99 - 109.

Gates, D. M. 1968 Transpiration and leaf temperature. Ann. Rev. Plant Physiol. 19:211-238.

Gates, D. M., R. Alderfer, and E. Taylor 1968 Leaf temperatures of desert plants. Science 159:994-995.

Gates, K. H., L. A. Stoddart, and C. W. Cook 1956 Soil as a factor influencing plant distribution on salt-deserts of Utah. Ecol. Monogr. 26:155-175.

Gibble, W. P. 1950 Nineteen years of vegetational change in a desert habitat. Master's Thesis, Univ. Ariz. (Tucson) 20 p.

Gile, L. H., F. F. Peterson, and R. B. Grossman 1966 Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Sci. 101:347-360.

Ginzburg, C. 1966 Xerophytic structures in roots of desert shrubs. Annals of Bot. 30:403-418.

Gissel-Nielsen, G., and A. J. Andersen 1967 Effects of fertilization on the strontium-calcium and caesium-potassium relationships in plants. p. 168-178. In Yearbook, Royal Veterinary and Agr. Coll., Copenhagen, Denmark.

Golomedova, T. I. 1959 The structure of underground organs of some semidesert plants. Bot. Zhur. 44:394-400.

Goodall, D. W. 1952 Quantitative aspects of plant distribution. Biol. Rev. 27:194-245.

Goodall, D. W. 1966 The nature of the mixed community. Ecol. Soc. Aust., Proc. I:84-96.

Goodall, D. W. 1970 Statistical plant ecology. Ann. Rev. Ecol. Syst. 1: 99-124.

Goodin, J. R., and C. M. McKell 1969 New ideas for the management and utilization of arid land forage plants. Int. Conf. Arid Lands in a Changing World, Abstr. (Tucson, Ariz.) June 3 - 13.

Goodman, L. A., and W. H. Kruskal 1954 Measure of association for cross classification. Jour. Amer. Statist. Assoc. 49:732-764.

Goodman, L. A., and W. H. Kruskal 1963 Measures of association for cross classifications: III. Approximate sampling theory. Ibid. 58:310-363.

Goodwin, D. L. 1956 Autecological studies of *Artemisia tridentata* Nutt. Ph. D. Thesis, State Coll. Wash. (Pullman). 72 p. Univ. Microfilms, Ann Arbor, Mich. (Diss. Abstr. 17,506).

Goss, J. A., and E. M. Romney 1959 Effects of bicarbonate and some other anions on the shoot content of P32, Ca45, Fe59, Rb86, Sr90, Ru106, Cs137, and Ce144 in bean and barley plants. Plant and Soil X:233-241.

Gould, F. W. 1951 Grasses of southwestern United States. Ariz. Agr. Exp. Sta. Biol. Sci. Bull. no. 7.

Gray, R., and J. Bonner 1948 An inhibitor of plant growth from the leaves of *Encelia farinosa*. Amer. Jour. Bot. 35:52-57.

Greenway, H., and C. B. Osmond 1970 Ion relations, growth, and metabolism of *Atriplex* at high external electrolyte concentrations. p. 49-56. *In* R. Jones (ed.) Studies of the Australian Arid Zone—The Biology of *Atriplex*. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ., Canberra, Australia.

Greig-Smith, P. 1964 Quantitative Plant Ecology (2nd ed.). Butterworth and Co., Ltd., London.

Grieve, B. J., and E. O. Hellmuth 1970 Eco-physiology of western Australian plants. Ecol. Plant. Gauthier-Villar, V:33-68.

Griffiths, D. 1901 Range improvement in Arizona. USDA Bur. Plant Ind. Bull. 4. 31 p.

Griffiths, D. 1904 Range investigations in Arizona. Ibid., no. 67. 62 p.

Griffiths, D. 1910 A protected stock range in Arizona. Ibid., no. 177.

Gunckel, J. E., and A. H. Sparrow 1961 Ionizing radiations: biochemical, physiological and morphological aspects of their effects on plants. Encyclo. Plant Physiol. 16:555-611.

Haas, A. R. C. 1947 Rainfall distribution under Fuerte avocado trees. Calif. Avocado Soc., Yearbook 1947:47-50.

Hammond, P. B., and A. L. Aronson 1964 Lead poisoning in cattle and horses in the vicinity of a smelter. Annals N. Y. Acad. Sci. 111:595-611.

Hanes, T. L. 1969 Comparisons of postfire succession in coastal and desert chaparral of Southern California. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 84.

Hanson, H. C. 1958 Principles concerned in the formation and classification of communities. Bot. Rev. 24:65-125.

Hanson, H. C., and E. D. Churchill 1961 The Plant Community. Reinhold Publ. Corp. New York. 218 p.

Hanson, W. C. 1967 Cesium-137 in Alaskan lichens, caribou and Eskimos. Health Phys. 13:383-389.

Hanson, W. C., and H. E. Palmer 1965 Seasonal cycle of ^{137}Cs in some Alaskan natives and animals. Ibid. 11:1401-1466.

Hansson, G., and A. Kylin 1969 Na$^+$-K$^+$-dependent ATPase activity of sugarbeet homogenates. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 248.

Hardy, R. W. F., R. D. Holsten, E. K. Jackson, and R. C. Burns 1968 The acetylene-ethylene assay for N$_2$ fixation: Laboratory and field evaluation. Plant Physiol. 43:1185-1207.

Harley, J., et al. 1970 (rev.) New York Operations Office Manual of Standard Procedures. NYO-4700 E-Cs-01-01.

Harris, F. S. 1914 The effect of soil moisture, plant food, and age on the ratio of tops to roots in plants. Jour. Amer. Soc. Agron. 22:65-75.

Hastings, J. R. 1959 Vegetation change and arroyo cutting in southeastern Arizona during the past century: an historical review. Jour. Ariz. Acad. Sci. 1:160-167.

Hastings, J. R. 1963 Historical changes in the vegetation of a desert region. Ph. D. Thesis, Univ. Ariz. (Tucson) 499 p.

Hastings, J. R., and R. M. Turner 1965 The Changing Mile; an Ecological Study of Vegetation Change of Time in the Lower Mile of an Arid and Semi-arid Region. Univ. Ariz. Press, Tucson. 317 p.

Hatch, M. D., and C. R. Slack 1966 Photosynthesis by sugar-cane leaves. A new carboxylation reaction and the pathway of sugar formation. Biochem. Jour. 101:103-111.

Hatch, M. D., and C. R. Slack 1970 Photosynthetic CO_2-fixation pathways. Ann. Rev. Plant Physiol. 21:141-162.

Hatch, M. D., C. R. Slack, and H. S. Johnson 1967 Further studies on a new pathway of photosynthetic carbon dioxide fixation in sugar-cane and its occurrence in other plant species. Biochem. Jour. 102:417-422.

Hawthorne, H. A. 1965 Fission product cycles in an agricultural system. I. Sample heterogeniety. p. 711-722. In A. W. Klement, Jr. (ed.) Radioactive Fallout from Nuclear Weapons Tests. USAEC Report CONF-765.

Heaslip, Margaret B. 1959 Effects of seed irradiation on germination and seedling growth of certain deciduous trees. Ecology 40:383-388.

Hellmuth, E. O. 1969 Eco-physiological studies on plants in arid and semi-arid regions in western Australia. Jour. Ecol. 57:613-634.

Hill, H. O. 1965 Composition of the shrub community. Ecol. Soc. Amer. Bull. (abstr.) 46:50.

Hilton, J. W. 1941 Effects of certain microecological factors on the germinability and early development of Eurotia lanata. Northwest Sci. 15: 86-92.

Hinds, W. T., and J. M. Thorp 1969 A climatogical survey of temperature-precipitation-vegetation relations on the ALE reserve. USAEC Annu. Rep. BNWL-2051 pt. 1 p. 65.

Hitchcock, C. L. 1932 Monograph of the genus Lycium. Annals Mo. Bot. Garden 19:179-364.

Hodge, C., and P. C. Duisberg 1963 Aridity and man; the challenge of the arid lands in the U.S. AAAS, Wash. Publ. no. 74, 584 p.

Holman, R. M., and W. W. Robbins 1939 A Textbook of General Botany. John Wiley and Sons, Inc. New York.

Horn, G. M., and O. Grisvold 1945 Phytochemical study of Larrea divaricata with special emphasis of its yellow pigments. Jour. Amer. Pharm. Assoc. 34:82-86.

Hsieh, J. J. C. 1968 The relationship of water potential and water content in a local soil. USAEC Annu. Rep. (1967) BNWL-714, p. 8.19-8.20.

Hull, A. C., Jr. 1962 Growth in the greenhouse of grasses and shrubs on soils from shadscale and sagebrush areas. Jour. Range Manage. 15:262-266.

Hull, A. C., and W. T. Vaughn 1951 Controlling big sagebrush with 2,4-D and other chemicals. Jour. Range Manage. 4:158-164.

Humphrey, R. R. 1933 A detailed study of desert rainfall. Ecology 14:31-34.

Humphrey, R. R. 1937 Ecology of the burroweed. Ibid. 18:1-9.

Humphrey, R. R. 1949 Fire as a means of controlling velvet mesquite, burroweed and cholla on southern Arizona ranges. Jour. Range Manage. 2:173-182.

Humphrey, R. R. 1953 The desert grassland, past and present. Ibid. 6: 159-164.

Humphrey, R. R. 1958 The desert grassland—a history of vegetation change and analysis of cause. Bot. Rev. 24:193-252.

Humphrey, R. R., A. L. Brown, and A. C. Everson 1956 Common Arizona range grasses. Ariz. Agr. Exp. Sta. Bull. 243.

Humphrey, R. R., and L. A. Mehrhoff 1958 Vegetation changes on a southern Arizona grassland range. Ecology 39:720-726.

Hunt, C. B. 1966 Plant ecology of Death Valley, California. U.S. Geol. Surv. Prof. Paper 509. 68 p.

Hurlbert, S. H. 1969 A coefficient of interspecific association. Ecology 50:1-9.

Hussaim, Ijaz 1966 Preliminary studies of germination requirements of shadscale (A. confertifolia). Jour. Range Manage. 20:329.

Hutchings, S. S. 1969 Vegetation and animal responses under winter grazing by sheep in the Great Basin salt-desert shrub type. Int. Conf. Arid Lands in a Changing World, Abstr. (Tucson, Ariz.) June 3-13.

Hyder, D. N. 1953 Controlling big sagebrush with growth regulators. Jour. Range Manage. 6:109-116.

Ichikawa, S., and A. H. Sparrow 1967 Radiation-induced loss of reproductive integrity in the stamen hairs of a polyploid series of Tradescantia species. Radiat. Bot. 7:429-441.

Ichikawa, S., and A. H. Sparrow 1968 The use of induced somatic mutations to study cell division rates in irradiated stamen hairs of Tradescantia virginiana L. Japan. Jour. Genet. 43:57-63.

Jaeger, E. 1940 Desert Wildflowers. Oxford Univ. Press. London. 322 p.

Jaeger, E. 1955 The California Deserts (3rd ed.). Stanford Univ. Press. Stanford, California. 211 p.

Jaeger, E. C. 1948 Who trims the creosote bush? Jour. Mammal. 29:187-188.

Jaeger, E. C. 1957 The North American Deserts. Stanford Univ. Press. Stanford, California. 308 p.

Jaeger, E. C. 1965 The California Deserts, from Death Valley to the Mexican Border. Stanford Univ. Press. Stanford, California. 207 p.

Jameson, D. A. 1966 Pinyon-juniper litter reduces growth of blue grama. Jour. Range Manage. 19:214-217.

Jardine, J. T., and M. Anderson 1919 Range management on the national forests. USDA Bull. 790, 97 p.

Jensen, H. L. 1965 Nonsymbiotic nitrogen fixation. In W. V. Bartholomew and F. E. Clark (eds.) Soil Nitrogen. Amer. Soc. Agron. Monogr. 10: 440.

Johnson, D. E. 1961 Edaphic factors affecting the distribution of creosotebush, Larrea tridentata (DC) Cav., in desert grassland sites of southeastern Arizona. Master's Thesis, Univ. Ariz. (Tucson). 58 p.

Johnson, Hilary S., and M. D. Hatch 1968 Distribution of the C_4-dicarboxylic acid pathway of photosynthesis and its occurrence in dicotyledonous plants. Phytochemistry 7:375-380.

Johnson, M. S., and D. E. Hibbard 1957 Geology of the Atomic Energy Commission Nevada proving grounds area, Nevada. U.S. Geol. Surv. Bull. 1021-K, p. 333-384.

Johnson, W. M. 1969 Life expectancy of a sagebrush control in central Wyoming. Jour. Range Manage. 22:177-182.

Johnston, I. M. 1940 The floristic significance of shrubs common to North and South American deserts. Jour. Arnold Arb. 21:356-363.

Johnstone, G. R., and F. W. Klepinger 1967 The effects of gamma radiation on germination and seedling development of Yucca brevifolia Engelm. Radiat. Bot. 7:385-388.

Jones, R., and K. C. Hodgkinson 1970 Root growth of rangeland chenopods: morphology and production of Atriplex nummularia and Atriplex vesicaria. p. 77-85. In R. Jones (ed.) Studies of the Australian Arid Zone—The Biology of Atriplex. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ. Canberra, Australia.

Jones, R., K. C. Hodgkinson, and A. J. Rixon 1970 Growth and productivity in rangeland species of Atriplex. p. 31-46. Ibid.

Kaaz, H. W., A. Wallace, and E. M. Romney 1971 Effect of a chronic exposure to gamma radiation on the shrub Ephedra nevadensis in the northern Mojave Desert. Radiat. Bot. 11:33-37.

Kassas, M. 1966 Plant life in deserts. p. 145-180. In E. S. Hills (ed.) Arid Lands. Methuen & Co., Ltd. London.

Kearney, T. H., L. J. Briggs, H. L. Shantz, J. W. McLane, and R. L. Piemeisel 1914 Indicator significance of vegetation in Tooele Valley, Utah. Jour. Agr. Res. 1:365-416.

Kearney, T. H., and R. H. Peebles 1960 Arizona Flora (2nd ed.). Univ. Calif. Press, Berkeley, Calif. 1085 p.

Kershaw, K. A. 1964 Quantitative and Dynamic Ecology. Edward Arnold, Ltd., London.

Kerster, H. W. 1968 Population age structure in the prairie forb, Liatris aspera. BioScience 18:430-432.

Khudairi, A. K. 1969 Mycorrhiza in desert soils. Ibid. 19:598-599.

Klemmedson, J. O., and R. B. Ferguson 1968 Response of bitterbush seedlings to nitrogen and moisture on a granitic soil. Agron. Abstr. 1968:136.

Knipe, D., and C. H. Herbel 1966 Germination and growth of some semidesert grassland species treated with aqueous extract from creosotebush. Ecology 47:775-781.

Knipe, O. D. 1960 The effect of aqueous extracts of creosotebush on germination and growth of some desert plains grassland plants. Master's Thesis, New Mexico State Univ. (University Park).

Knipe, O. D. 1967 Influence of temperature on the germination of some range grasses. Jour. Range Manage. 20:298-299.

Knipe, O. D. 1968 Effects of moisture stress on germination of alkali sacaton, galleta, and blue grama. Ibid. 21:3-4.

Koch, B., and H. J. Evans 1966 Reduction of acetylene to ethylene by soybean roots. Plant Physiol. 41:1748-1757.

Koeppe, D. E., and R. J. Miller 1970 Lead effects on corn mitochondrial respiration. Science 167:1376-1378.

Kohn, H. I., G. C. McLeod, and K. A. Wright 1967 Inhibition of chlorophyll A and B synthesis in Chlamydomonos reinhardi mutant strain Y-2 by ionizing radiation. Radiat. Bot. 7:123-127.

Koller, D. 1968 The physiology of dormancy and survival of plants in desert environments. Soc. Exp. Biol., Symp. 23:1-42.

Koller, D. 1970 Determination of fundamental plant parameters controlling carbon assimilation and transpiration by the null-point compensating system (improved version). USAEC Report UCLA 12-797. 28 p.

Koller, D. 1970 The partitioning of resistances to photosynthetic CO_2 uptake in the leaf. New Phytol. 69:971-981.

Koller, D., and Y. Samish 1964 A null-point compensating system for simultaneous and continuous measurement of net photosynthesis and transpiration by controlled gas-stream analysis. Bot. Gaz. 125:81-85.

Koranda, J. J. 1967 Residual tritium at Sedan crater. USAEC Report CONF-670503. p. 696-708.

Kruckeberg, A. R. 1969 Soil diversity and the distribution of plants, with examples from western North America. Madroño 20:129-154.

Ku, Lily Lim, and R. J. Romani 1966 Ribosomes from pear fruit. Science 154:408-410.

Kunze, R. E. 1903 The desert flora of Phoenix, Arizona. Torrey Bot. Club Bull. 30:302-307.

Kurtz, E. B. 1961 A chemical basis for the adaptation of plants. In L. M. Shields and J. L. Gardner (eds.) Bioecology of the Arid and Semiarid Lands of the Southwest. New Mexico Highlands Univ. Bull. 212.

Lambert, J. M., and M. B. Dale 1964 The use of statistics in phytosociology. Advances Ecol. Res. 2:55-99.

Lange, O. L. 1965 The heat resistance of plants, its determination and viability. p. 399-405. In F. E. Eckhardt (ed.) Methodology of Plant Ecophysiology. UNESCO. Paris.

Langford, A. N., and M. F. Buell 1969 Integration, identity and stability in the plant association. Advances Ecol. Res. 6:83-135.

Larson, K. H. 1959 Summary of observations of distribution, characteristics and biological availability of fallout originating from continental detonations. p. 803-830. In Hearings, Joint Comm. on Atomic Energy, U.S. Congress, Biol. Effects of Nuclear War, Washington, D.C.

Larson, K. H. 1963 Continental close-in fallout: Its history, measurement and characteristics. p. 19-26. In V. Schultz and A. W. Klement, Jr. (eds.) Radioecology. Reinhold Publ. Corp. New York.

Larson, K. H., et al. 1966 Distribution, characteristics, and biotic availability of fallout (Operation Plumbbob). USAEC Report WT-1488.

Larson, K. H., H. A. Hawthorne, and J. H. Olafson 1962 Nevada Test Site fallout: Some characteristics, its apparent environmental equilibrium and biological availability. In A. W. Klement, Jr. (ed.) Radioactive Fallout from Nuclear Weapons Tests. USAEC Report TID-7632. Book 1, p. 4-24.

Larson, K. H., J. W. Neel, and associates 1960 Summary statement of findings related to the distribution, characteristics and biological availability of fallout debris originating from testing programs at the Nevada Test Site. In Fallout from Nuclear Weapons Tests. Joint Committee on atomic energy. (USAEC Report UCLA-438).

Larson, K. H., J. H. Olafson, H. M. Mork, and D. R. Howton 1952 Field observations and preliminary field data obtained by the UCLA survey group, Operation Jangle, Nov. 1951. USAEC Report UCLA-182. 29 p.

Lawrence, D. B., et al. 1967 The role of Dryas drummondii in vegetation development following ice recession at Glacier Bay, Alaska, with special reference to its nitrogen fixation by root nodules. Jour. Ecol. 55:793-813.

Leigh, J. H., and A. D. Wilson 1970 Utilization of Atriplex species by sheep. p. 97-104. In R. Jones (ed.) Studies of the Australian Arid Zone—The Biology of Atriplex. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ. Canberra, Australia.

Leonard, C. D. 1950 Sodium as a fertilizer for New Jersey soils. New Jersey Agr. Exp. Sta. Bull. 752.

Leopold, A. S. 1961 The Desert. Time Inc. New York. 192 p.

Lewis, M. C. 1969 Genecological differentiation and adaptive significance of leaf structure in relation to xeric environments. 11th Int. Bot. Congr. Abstr. (Seattle) Aug. 24 - Sept. 2. p. 128.

Liden, K., and M. Gustafsson 1966 Relationships and seasonal variation of ^{137}Cs in lichen, reindeer and man in northern Sweden, 1961-1965. p. 193-208. In B. Aberg and F. P. Hungate (eds.) Radioecological Concentration Processes. Pergamon Press. Oxford.

Lindberg, R. G., and K. H. Larson 1956 The short term biological fate and persistence of radioactive fallout as measured at various locations within fallout patterns. p. 197-204. In G. M. Dunning and J. A. Hilchen (eds.) Shorter-Term Biological Hazards of a Fallout Field. USAEC and Dept. of Defense, Washington, D.C.

Lindberg, R. G., E. M. Romney, J. H. Olafson, and K. H. Larson 1959 The factors influencing the biological fate and persistence of fallout (Operation Teapot). USAEC Report WT-1177. 78 p.

Lindberg, R. G., J. T. Scanlan, J. C. Watson, W. A. Rhoads, and K. H. Larson 1954 Environmental and biological fate of fallout from nuclear detonations in areas adjacent to the Nevada Proving Grounds, Operation Upshot-Knothole. USAEC Report WT-812. 49 p.

Livingston, B. E. 1910 Relation of soil moisture to desert vegetation. Bot. Gaz. 50:241-256.

Lowe, C. H., Jr. 1961 Biotic communities in the sub-Mogollon region of the inland southwest. Jour. Ariz. Acad. Sci. 2:40-49.

Lucas, A. C., Z. G. Burson, and R. E. Lagerquist 1966 Design of a shielded source for the irradiation of natural animal populations. USAEC Report CEX-63.10, CETO.

Lucas, A. C., and N. R. French 1966 A miniature thermoluminescent dosimeter and its application. Int. Conf. Luminescence Dosimetry, Proc. (Stanford Univ.) June 1965.

Lund, C. R., Sr., and C. D. McKnight 1963 Technical Report N.T.S.F. #1006. Multi-purpose Irradiator, Reynolds Electrical and Eng. Co., Mercury, Nevada.

Lyon, L. J. 1968 An evaluation of density sampling methods in a shrub community. Jour. Range Manage. 21:16-20.

MacDougal, D. T. 1912 The water balance of desert plants. Annals Bot. 26:71-93.

Mallery, T. D. 1935 Changes in the osmotic value of the expressed sap of leaves and twigs of Larrea tridentata as influenced by environmental conditions. Ecol. Monogr. 5:1-35.

Markle, M. S. 1917 Root systems of certain desert plants. Bot. Gaz. 64: 177-205.

Marten, G. C., and P. B. Hammond 1966 Lead uptake by bromegrass from contaminated soils. Agron. Jour. 58:553-554.

Martin, W. E. 1962 Applications of fundamental biology to the needs of man. 4. Radioecology and the study of environmental radiation. USAEC Report TID-16060. 70 p.

Martin, W. E. 1962 Immediate effects of a nuclear detonation on desert vegetation. Ecol. Soc. Amer. Bull. 43:123-124.

Martin, W. E. 1963 Close-in effects of an underground nuclear detonation on vegetation. I. Immediate effects of cratering, throw-out, and blast (Project Sedan). USAEC Report PNE-228F. 41 p.

Martin, W. E. 1963 Loss of I^{131} from fallout-contaminated vegetation. Health Phys. 9:1141-1148.

Martin, W. E. 1963 Notes on the deposition of fallout in relation to topography and local meteorological conditions. USAEC Report UCLA 12-513.

Martin, W. E. 1964 Losses of Sr^{89} and Sr^{90}, and I^{131} from fallout-contaminated plants. Radiat. Bot. 4:275-284.

Martin, W. E. 1964 Radioecology and the study of environmental radiation. Torrey Bot. Club. Bull. 91:283-323.

Martin, W. E. 1965 Early food-chain kinetics of radionuclides following close-in fallout from a single nuclear detonation. In A. W. Klement, Jr.

(ed.) Radioactive Fallout from Nuclear Weapons Tests. USAEC Report CONF-765. p. 758-782.

Martin, W. E. 1965 Interception and retention of fallout by desert shrubs. Health Phys. 11:1341-1354.

Martin, W. E. 1965 Interception and retention of radioactive fallout by desert shrubs in the Sedan fallout field. USAEC Report PNE-238F. 40 p.

Martin, W. E. 1965 Radiation facilities and objectives. Ecol. Soc. Amer. Bull. (abstr.) 46:39.

Martin, W. E. 1966 Close-in effects of nuclear excavation and radiation on desert vegetation. p. 7-9. *In* G. A. Sacher (ed.) Radiation Effects on Natural Population. Div. of Biol. Med. Res., Argonne Nat. Lab., Lemont, Ill.

Martin, W. E., and F. B. Turner 1963 Increased environmental radiation in southern Nevada, October - December, 1961. USAEC Report UCLA 12-518. 45 p.

Martin, W. E., and F. B. Turner 1965 Food-chain relationships of radiostrontium in the Sedan fallout field. USAEC Report PNE-237F. 61 p.

Martin, W. E., and F. B. Turner 1966 Transfer of Sr^{89} from plants to rabbits in a fallout field. Health Phys. 12:621-631.

Mason, H. L. 1946 The edaphic factor in narrow endemism: I. The nature of environmental variables. Madroño 8:209-226.

Mathias, M. E. 1961 Ornamentals for low elevation desert areas of Southern California. Calif. Agr. Expt. Sta., Circ. 496:4-36.

Maxey, G. B. 1968 Hydrogeology of desert basins. Ground Water 6:10-22.

Mayland, H. F., and T. H. McIntosh 1966 Availability of biologically-fixed atmospheric nitrogen-15 to higher plants. Nature 209:421-422.

Mayland, H. F., T. H. McIntosh, and W. H. Fuller 1966 Fixation of isotopic nitrogen in a semi-arid soil by algae crust organisms. Soil Sci. Soc. Amer., Proc. 30:56-60.

McBride, T. H. 1905 The Alamogordo Desert. Science 21:90-97.

McCormick, J. F., and R. B. Platt 1962 Effects of ionizing radiation on a natural plant community. Radiat. Bot. 2:161-188.

McDonald, C. C., and G. H. Hughes 1968 Studies of consumptive use of water by phreatophytes and hydrophytes near Yuma, Arizona. U.S. Geol. Surv., Prof. Paper 486-F. 24 p.

McGinnies, W. G. 1934 The relation between frequency index and abundance as applied to plant populations in a semi-arid region. Ecology 15: 263-282.

McGinnis, J. T. 1963 Effects of radiation from an air shielded reactor on forest litter production. p. 283-288. *In* V. Schultz and A. W. Klement, Jr. (eds.) Radioecology. Reinhold Publ. Corp. New York.

McIntosh, R. P. 1967 The continuum concept of vegetation. Bot. Rev. 33: 130-187.

McKell, C. M., and J. R. Goodin 1969 New uses for arid range plants. Int. Conf. Arid Lands in a Changing World (Tucson, Ariz.) June 3 - 13.

McKell, C. M., J. R. Goodin, and C. Duncan 1969 Chaparral manipulation affects soil moisture depletion patterns. Jour. Range Manage. 22: 159-168.

McKelvey, S. D. 1938, 1947 Yuccas of the Southwestern United States. Harvard Univ., Arnold Arborerum, 2 vols.

McMillan, C. 1969 Ecotypes and ecosystem function. BioScience 19:131-134.

McNaughton, S. J. 1968 Autotoxic feedback in relation to germination and seedling growth in *Typha latifolia.* Ecology 49:367-369.

McNaughton, S. J. 1968 Structure and function in California grasslands.

Ecology 49:962-972.

McNulty, I. 1969 The effect of NaCl on ionic and osmotic balance of a halophyte. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 135.

McPherson, J. K., and C. H. Muller 1969 Allelopathic effects of *Adenostoma fasciculatum* in the California chaparral. Ibid.

Mehrhoff, L. A. 1955 Vegetation changes on a southern Arizona grassland range—an analysis of causes. Master's Thesis, Univ. Ariz. (Tucson)

Micke, A. 1966 Modification of radiosensitivity in seeds of different plant species by secondary factors. Symp. Mech. Mutat. Inducing Factors, Proc. (Prague) 1965. p. 27-29.

Migahid, A. M. 1961 The drought resistance of Egyptian desert plants. *In* Arid Zone Research—XVI. Plant-water relationships in arid and semi-arid conditions. Proc. Madrid Symp. UNESCO, Paris. p. 213-233.

Millar, C. E., L. M. Turk, and H. D. Foth 1965 Nutrient requirements and mineral nutrition of plants. p. 288-313. *In* Fundamentals of Soil. John Wiley & Sons, Inc. New York.

Miller, R. B. 1968 Flows and cycles of macro- and micro-elements in a forest soil and its environment. 9th Int. Congr. Soil Sci., Trans. (Adelaide, Australia). 4:323-331.

Mills, H. L., and L. M. Shields 1961 Root absorption of fission products by *Bromus rubens* L. from the AEC Nevada Test Site soil contaminated by an underground nuclear explosion. Radiat. Bot. 1:84-91.

Milthorpe, F. L. 1970 *Atriplex*—Atlantean or Atrabilarian. p. 123-125. *In* R. Jones (ed.) Studies of the Australian Arid Zone—The Biology of *Atriplex*. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ. Canberra, Australia.

Mitchell, J. E., N. E. West, and R. W. Miller 1966 Soil physical properties in relation to plant community patterns in the shadscale zone of northwestern Utah. Ecology 47:627-630.

Moës, A. 1961 Water content, wave-length and sensitivity to X-rays in barley. Symp., The Effects of Ionizing Radiation on Seeds and their Significance for Crop Improvement. (Vienna) p. 632-641. IAEA and FAO.

Moore, C. W. E. 1970 A model for rangelands research. p. 127-128. *In* R. Jones (ed.) Studies of the Australian Arid Zone—The Biology *Atriplex*. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ., Canberra, Australia.

Mooring, Molly T., A. W. Cooper, and E. D. Seneca 1971 Seed germination response and evidence for height ecophenes in *Spartina alterniflora* from North Carolina. Amer. Jour. Bot. 58:48-55.

Mork, H. M., et al. 1966 Characteristics of fallout from a deeply buried nuclear detonation from 7 to 70 miles from ground zero. USAEC Report PNE-225F. 114 p.

Mork, H. M., R. W. Farmer, and K. A. Flygare Improved feedback control for the null-point compensating system. Soil Sci. (in press).

Muench, J. R. 1943 Our desert yuccas. Natur. Hist. 51:142-145.

Muhktar, H. A. M. 1961 Factors affecting seed germination of some important desert plants. Master's Thesis, Univ. Ariz. (Tucson). 54 p.

Mukerji, S. K., and I. P. Ting 1969 Malic dehydrogenase isoenzymes in green stem tissue of *Opuntia*: isolation and characterization. Arch. Biochem. Biophys. 131:336-351.

Muller, C. 1967 Significance of allelopathy for the composition of vegetation. Z. Pflanzenkr. Pflanzenschuta 74:333-346. (Ger.). Cf. Chem. Abstr. 68:863n (1968).

Muller, C. H. 1953 The association of desert annuals with shrubs. Amer.

Jour. Bot. 40:53-60.

Muller, C. H. 1966 The role of chemical inhibition (allelopathy) in vegetational composition. Torrey Bot. Club, Bull. 93:332-351.

Muller, W. H., and C. H. Muller 1956 Association patterns involving desert plants that contain toxic products. Amer. Jour. Bot. 43:354-361.

Munz, P. A. 1962 California Desert Wildflowers. Univ. Calif. Press. Berkeley. 122 p.

Munz, P. A. 1968 Supplement of A California Flora. Univ. Calif. Press. Berkeley.

Munz, P. A., and D. D. Keck 1959 A California Flora. Univ. Calif. Press. Berkeley.

Mutch, R. W. 1969 Wildland fires and ecosystems—a hypothesis. Ecol. Soc. Amer., Bull. 50:102.

Nakao, M., et al. 1967 Molecular weight of Na, K-sensitive ATPase approximated by the radiation inactivation method. Biochem. Biophys. Res. Comm. 29:588-592.

Naqui, H. H. 1969 Allelopathic effects of Lolium multiflorum. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 156.

Neel, J. W., and K. H. Larson 1963 Biological availability of Sr^{90} to small native animals in fallout patterns from the Nevada Test Site. p. 45-50. In A. W. Klement, Jr. (ed.) Radioecology. Reinhold Publ. Corp. New York.

Neess, J. C., R. C. Dugdale, J. J. Goering, and Vera A. Dugdale 1963 Use of nitrogen-15 for measurement of rates in the nitrogen cycle. p. 481-484. In V. Schultz and A. W. Klement, Jr. (eds.) Radioecology. Reinhold Publ. Corp. New York.

Negbi, M., and M. Evenari 1961 The means of survival of some desert summer annuals. In Arid Zone Research—XVI. Symp. Plant-water relationships in arid and semi-arid conditions. UNESCO, Paris. p. 249-259.

Negbi, M., and B. Tamari 1963 Germination of chlorophyllous and achlorophyllous seeds of Salsola volkensii and Aellenia autrani. Israel Jour. Bot. 12:124-135.

Nichol, A. A. 1937 The Natural Vegetation of Arizona. Ariz. Agr. Exp. Sta. Tech. Bull. 68:181-222.

Nichol, A. A. 1952 The Natural Vegetation of Arizona (2nd ed.). Ariz. Agr. Exp. Sta. Tech. Bull. 127:189-230.

Nishita, H., R. M. Haug, and M. Hamilton 1968 Influence of minerals on Sr^{90} and Cs^{137} uptake by bean plants. Soil Sci. 105:237-243.

Nishita, H., B. W. Kowalewsky, A. J. Steen, and K. H. Larson 1956 Fixation and extractability of fission products and contaminating various soils and clays: I. Sr90, Y91, Ru106, Cs137, and Ce144. Soil Sci. 81:317-326.

Nishita, H., and W. A. Rhoads 1970 Ecological and environmental effects from local fallout from Schooner. USAEC Report CEP-68.5. 21 p.

Nishita, H., E. M. Romney, G. V. Alexander, and K. H. Larson 1960 Influence of K and Cs on release of Cs137 from three soils. Soil Sci. 89:167-176.

Nishita, H., E. M. Romney, and K. H. Larson 1961 Uptake of radioactive fission products by crop plants. Agr. Food Chem. 9:101-106.

Nishita, H., E. M. Romney, and K. H. Larson 1965 Uptake of radioactive fission products by plants. p. 55-81. In E. B. Fowler (ed.) Radioactive Fallout, Soils, Plants, Foods, Man. Elsevier Publ. Co. New York.

Nishita, H., A. J. Steen, K. H. Larson 1958 Release of Sr90 and Cs137 from Vina loam upon prolonged cropping. Soil Sci. 86:195-201.

Nishita, H., and P. Taylor 1964 Influence of stable Sr and Ca on Sr90 and Ca45 in soils and clay minerals. Ibid. 98:181-186.

Nishita, H., P. Taylor, G. V. Alexander, and K. H. Larson 1962 Influence of stable Cs and K on the reactions of Cs137 and K42 in soils and clay materials. Ibid. 94:187-197.

Nord, E. C., D. R. Christensen, and A. P. Plummer 1969 Atriplex species (or taxa) that spread by root sprouts, stem layers, and by seed. Ecology 50:324-326.

Nordyke, M. D., and M. M. Williamson 1965 The Sedan event. USAEC Report PNE-242F. 103 p.

Oertli, J. J., and W. F. Richardson 1970 Mechanism of boron immobility in plants. Physiol. Plant. 23:108-116.

Olafson, J. H., J. W. Neel, C. J. Spiegl, R. H. Wilson, F. G. Lowman, and K. H. Larson 1953 Preliminary study of off-site, air-borne radioactive materials, Nevada proving grounds: I. Fallout origination from Snapper 6, 7, and 8 at distances of ten to fifty miles from ground zero. USAEC Report UCLA-243. 123 p.

O Leary, J. W. 1966 Temperature effects on root pressure exudation. Annals of Bot. 30:419-423.

Olsen, S. R., C. V. Cole, F. S. Watanabe, and L. A. Dean 1954 Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. 939.

Olson, J. S. 1965 Equations of cesium transfer in Liriodendron forest. Health Phys. 11:1385-1392.

Oppenheimer, H. R. 1960 Adaptation to drought: xerophytism. In Arid Zone Research–XV. Symp. Plant-water relationships in arid and semiarid conditions. Reviews of research. UNESCO, Paris. p. 105-138.

Osmond, C. B. 1963 Oxalates and ionic equilibria in Australian saltbush (Atriplex). Nature 198:503-504.

Osmond, C. B. 1968 Divalent cation absorption and interaction in Atriplex. Austral. Jour. Biol. Sci. 21:37-48.

Osmond, C. B. 1968 Ion absorption in Atriplex leaf tissue: I. Absorption by mesophyll cells. Ibid. 21:1119-1130.

Osmond, C. B. 1970 Carbon metabolism in Atriplex leaves. p. 17-21. In R. Jones (ed.) Studies of the Australian Arid Zone–The Biology of Atriplex. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ. Canberra, Australia.

Osmond, C. B., and P. N. Avadhani 1968 Acid metabolism in Atriplex: II. Oxalate synthesis during acid metabolism in the dark. Austral. Jour. Biol. Sci. 21:917-927.

Pallahgy, C. K. 1970 Salt relations of Atriplex leaves. p. 57-62. In R. Jones (ed.) Studies of the Australian Arid Zone–The Biology of Atriplex. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ. Canberra, Australia.

Parker, J. 1956 Drought resistance in woody plants. Bot. Rev. 22:241-289.

Pase, C. P. 1966 Grazing and watershed value of native Arizona plants. In Native Plants and Animals as Resources in Arid Lands of the Southwestern United States. AAAS, Rocky Mountain & Southwest, Div. Contrib. 8:31-40.

Passey, H. B., and V. K. Hugie 1962 Sagebrush on relict ranges in the Snake River plains and northern Great Basin. Jour. Range Manage. 15:273-278.

Patten, D. T. 1968 Succession from sagebrush to mixed conifer forest in the northern Rocky Mountains. Ecol. Soc. Amer., Bull. (abstr.) 49:111.

Pechanec, J. F., G. Stewart, A. P. Plummer, J. H. Robertson, and A. C. Hull, Jr. 1954 Controlling sagebrush on rangelands. USDA Farmer's Bull. 2072, 36 p.

Pedigo, R. A. 1963 Effects of ionizing radiation on Pinus taeda (E). p. 295-300. In V. Schultz and A. W. Klement (eds.) Radioecology. Reinhold Publ. Corp. New York.

Petrov, M. P. 1970 Deserts of Asia. p. 279-302. In H. E. Dregne (ed.) Arid Lands in Transition. AAAS Publ. no. 90. Washington, D.C.

Piehl, M. A. 1969 Ecology and evolution of parasitic seed plants. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 170.

Pielou, E. C. 1969 An Introduction of Mathematical Ecology. Wiley-Interscience. New York.

Platt, R. B. 1962 Radiation and plant life. Discovery. Nov. 1962. 6 p.

Platt, R. B. 1963 Ecological effects of ionizing radiation on organisms, communities, and ecosystems. p. 243-256. In V. Schultz and A. W. Klement, Jr. (eds.) Radioecology. Reinhold Publ. Corp. New York.

Plummer, G. L., T. M. Pullen, Jr., and E. E. Provost 1967 Cesium-137 and a population of Georgia white-tailed deer. p. 609-615. 2nd Nat. Symp. Radioecol., Proc. (Ann Arbor, Mich.) May 15-17.

Poole, Faith N. 1958 Seed germination requirements of four desert tree species. Master's Thesis, Univ. Ariz. (Tucson). 31 p.

Prince, A. L. 1957 Trace element delivering capacity of 10 New Jersey soil types as measured by spectrographic analysis of soils and mature corn. Soil Sci. 84:413-418.

Quick, C. R., and Alice S. Quick 1961 Germination of Ceanothus seeds. Madroño 16:23-31.

Rainey, C. T., J. W. Neel, H. M. Mork, and J. H. Olafson 1954 Distribution and characteristics of fallout at distances greater than ten miles from ground zero (Operation Upshot/Knothole). USAEC Report WT-811.

Rasmussen, R. A., and F. W. Went 1965 Volatile organic material of plant origin in the atmosphere. Nat. Acad. Sci. (U.S.), Proc. 53:215-220.

Reichle, D. E., and D. A. Crossley, Jr. 1965 Radiocesium dispersion in a cryptozoan food web. Health Phys. 11:1375-1384.

Reichle, D. E., and D. A. Crossley, Jr. 1967 Tropic level concentrations of cesium-137, sodium, and potassium in forest arthropods. 2nd Nat. Symp. Radioecol., Proc. (Ann Arbor, Mich.) May 15 - 17. p. 678-686.

Reynolds, H. G., and J. W. Bohning 1956 Effects of burning on a desert grass-shrub range in southern Arizona. Ecology 37:769-777.

Rhoads, W. A., E. F. Frolich, and A. Wallace 1967 Russian thistle seeds. Calif. Agr. 21(7):2.

Rhoads, W. A., R. B. Platt, and R. A. Harvey 1969 Radiosensitivity of certain perennial shrub species based on a study of the nuclear excavation experiment, Palanquin, with other observations of effects on vegetation. USAEC Report CEX-68.4 CETO. 42 p.

Rhoads, W. A., R. B. Platt, R. A. Harvey, and E. M. Romney 1969 Ecological and environmental effects from local fallout from Cabriolet. I. Radiation doses and short-term effects on the vegetation from close-in fallout. USAEC Report PNE-956. 65 p.

Rhoads, W. A., H. L. Ragsdale, R. B. Platt, and E. M. Romney 1970 Radiation doses to vegetation from close-in fallout at Project Schooner. Symp. Survival of Food Crops and Livestock in the Event of Nuclear War. Sept. 15-18. Brookhaven Nat. Lab., New York.

Rickard, W. H. 1959 Gross vegetation patterns within the Nevada Test

Site. Jour. Colorado-Wyoming Acad Sci. (abstr.) 4:32.

Rickard, W. H. 1961 Notes on bird nests found in a desert shrub community following nuclear detonations. Condor 63:265-266.

Rickard, W. H. 1962 Phytosociological analysis in a desert shrub community following atomic explosions. USAEC Report HW-Sa-2546. 7 p.

Rickard, W. H. 1963 Vegetational analyses in a cresote bush community and their radioecologic implications. p. 39-44. *In* V. Schultz and A. W. Klement, Jr. (eds.) Reinhold Publ. Corp. New York.

Rickard, W. H. 1966 Accumulation of ^{137}Cs in litter and understory plants of forest stands from various climatic zones of Washington. p. 527-531. *In* B. Aberg and F. P. Hungate (eds.) Radioecological Concentration Processes. Pergamon Press. Oxford.

Rickard, W. H. 1969 The vegetation mosaic of the arid land ecology reserve in southeastern Washington. Int. Conf. Arid Lands in a Changing World, Abstr. (Tucson, Ariz.) June 3-13.

Rickard, W. H., and Janice C. Beatley 1965 Canopy-coverage of the desert shrub vegetation mosaic of the Nevada Test Site. Ecology 4:524-529.

Rickard, W. H., and J. F. Cline 1970 Fallout radiocesium in the Cascade Mountains of Washington. Battelle Northwest Lab. Annual Report 1306, Pt. 2 UC-48.

Rickard, W. H., and R. F. Keough 1968 Soil plant relationships of two steppe desert shrubs. Plant and Soil 29:205-213.

Rickard, W. H., and J. R. Murdock 1963 Soil moisture and temperature survey of a desert vegetation mosaic. Ecology 44:821-824.

Rickard, W. H., and L. M. Shields 1963 An early stage in the plant recolonization of a nuclear target area. Radiat. Bot. 3:41-44.

Riedl, W. A., K. H. Asay, J. L. Nelson, and G. M. Telwar 1964 Studies of *Eurotia lanata* (winterfat). Univ. Wyo. Agr. Exp. Sta., Bull. 425. 18 p.

Rigby, D. 1959 Desert drugstore. Ariz. Highways 35:28-33.

Rixon, A. J. 1970 Cycling of nutrients in a grazed *Atriplex vesicaria* community. p. 87-95. *In* R. Jones (ed.) Studies of the Australian Arid Zone—The Biology of *Atriplex*. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ. Canberra, Australia.

Robertson, J. H., and H. P. Cords 1956 Survival of big sagebrush of different ages after treatment with selective herbicides. Weeds 4:376-385.

Robertson, J. H., and H. P. Cords 1957 Survival of rabbitbrush, *Chrysothamnus* species, following chemical, burning, and mechanical treatments. Jour. Range Manage. 10:83-89.

Rogers, A. P., and S. S. Schevemmer 1968 Radiosensitivity studies with woody plants—I. Acute gamma irradiation survival data for 28 species and predictions for 190 species. Radiat. Bot. 8:149-186.

Rogowski, A. S., and T. Tamura 1970 Environmental mobility of cesium-137. Ibid. 10:35-45.

Rojas-M., P. and M. Rojas-Garcidueñas 1960 Notes on the distribution of the Russian thistle (*Salsola kali* L. var. *tenuifolia*) in Mexico. Weeds 8: 466-468.

Romani, R. J. 1964 Radiation physiology of fruit-respiration during and immediately following kilorad doses of ionizing radiation. Radiat. Bot. 4: 299-307.

Romani, R. J. 1966 Short communication. Electron spin resources in irradiated fruit. Ibid. 6:371-372.

Romani, R. J., and L. K. Fisher 1966 Mitochondrial resistance to massive irradiation *in vivo*. IV. Suppression and recovery in rate of amino acid incorporation into mitochondrial protein. Arch. Biochem. Biophys. 117:645-649.

Romani, R. J., Lily L. Ku, L. K. Fisher, and J. G. van Kooy 1966 Mitochondria: Increase in oxidative capacity and quantitative recovery after massive doses of ionizing radiation. Radiat. Res. 28:257-265.

Romani, R. J., and Ida K. Yu 1966 Mitrochondrial resistance to massive irradiation in vivo. III. Suppression and recovery of respiratory control. Arch. Biochem. Biophys. 117:638-644.

Romani, R. J., and Ida K. Yu 1968 Mitochondrial resistance to massive irradiation in vivo. V. Repair and the repair overshoot. Ibid. 127:283-287.

Romney, E. M., G. V. Alexander, G. M. LeRoy, and K. H. Larson 1959 Influence of stable Sr on plant uptake of Sr90 from soils. Soil Sci. 87:42-45.

Romney, E. M., G. V. Alexander, H. Nishita, and K. H. Larson 1961 Influence of Ca and Sr amendments on Sr90 uptake by Ladino clover upon prolonged cropping. Soil Sci. Soc. Amer., Proc. 25:299-301.

Romney, E. M., G. V. Alexander, W. A. Rhoads, and K. H. Larson 1959 Influence of calcium on plant uptake of Sr90 and stable strontium. Soil Sci. 87:160-165.

Romney, E. M., W. L. Ehrler, A. H. Lange, and K. H. Larson 1960 Some environmental factors influencing radiostrontium uptake by plants. Plant and Soil XII:41-48.

Romney, E. M., R. G. Lindberg, H. A. Hawthorne, B. G. Bystrom, and K. H. Larson 1963 Contamination of plant foliage with radioactive fallout. Ecology 44:343-349.

Romney, E. M., H. M. Mork, and K. H. Larson 1970 Persistence of plutonium in soil, plants, and small mammals. Health Phys. 19:487-491.

Romney, E. M., J. W. Neel, H. Nishita, J. H. Olafson, and K. H. Larson 1957 Plant uptake of Sr90, Y91, Ru106, Cs137, and Ce144 from soils. Soil Sci. 83:369-376.

Romney, E. M., H. Nishita, J. H. Olafson, and K. H. Larson 1963 Root transfer to fission products from contaminated soil. Soil Sci. Soc. Amer., Proc. 27:383-385.

Romney, E. M., H. Nishita, and A. Wallace 1960 Transfer of radioactive fallout debris. Calif. Agr. 14(3):6.

Romney, E. M., and W. A Rhoads 1966 Neutron activation products from Project Sedan in plants and soils. Soil Sci. Soc. Amer., Proc. 30:770-773.

Romney, E. M., A. J. Steen, R. A. Wood, and W. A. Rhoads 1966 Concentration of radionuclides by plants grown on ejecta from the Sedan thermonuclear cratering detonation. p. 391-398. In B. Aberg and F. Hungate (eds.) Radioecological Concentration Processes. Pergamon Press. Oxford.

Rosenthal, I. 1966 Distribution of the sample version of the measure of association, gamma. Jour. Amer. Statist. Assoc. 61:440-453.

Rosenzweig, M. L. 1968 Net primary productivity of terrestrial communities: Prediction from climatological data. The Amer. Natur. 102:67-74.

Rowland, R. H., and F. B. Turner 1966 Correlation of the local distributions of Dipodomys microps and D. merriami and of the annual grass Bromus rubens. Southwest. Natur. 9:56-61.

Runyon, E. H. 1934 The organization of the creosote bush with respect to drought. Ecology 15:128-138.

Runyon, E. H. 1936 Ratio of water content to dry weight in leaves of the creosotebush. Bot. Gaz. 97:518-553.

Rzedowsky, J., and F. M. Leal 1958 El limite sur de distribucion geografica de Larrea tridentata. Acta Cientifica Potosina 2:133-147.

Sanderson, H. R., R. L. Hubbard, and D. W. Seegrist 1963 Effects of grass competition on bitterbrush: Second-year report. US Forest Serv. Res. Note PSW-26.

Saul, W. E. 1955 A descriptive catalogue of the tree and larger woody shrubs of Utah based on the anatomy of the wood. Ph. D. Thesis, Univ. Utah (Salt Lake City).

Saunier, R. E., H. M. Hull, and J. H. Ehrenreich 1968 Aspects of the drought tolerance in creosotebush (*Larrea divaricata*). Plant Physiol. 43:401-404.

Schlatterer, E. F., and E. W. Tisdale 1970 Effects of litter of *Artemisia*, *Chrysothamnus*, and *Tortula* on germination and growth of three perennial grasses. Ecology 50:869-873.

Schmutz, E. M. 1963 Factors affecting the absorption, translocation, and toxicity of herbicides on creosotebush. Ph. D. Thesis, Univ. Ariz. (Tucson). Univ. Microfilms, Ann Arbor, Mich. (Diss. abstr. 63-6847). 175 p.

Schmutz, E. M., F. H. Tschirley, and R. M. Turner 1957 Chemical control of tree desert shrubs. Prog. Agr. Ariz. 9(1):14.

Schneider, K. 1967 Method for determination of the true carbon dioxide photosynthesis rates in higher plants. Z. Naturforsch., B 22:1364-1365 (Ger.). Cf. Chem. Abstr. 68:93539z (1968).

Schollhorn, R., and R. H. Burris 1967 Acetylene as a competitive inhibitor of N_2 fixation. Nat. Acad. Sci. (U.S.), Proc. 58:213-216.

Schultz, V. 1961 Off-site ecological research of the Division of Biology and Medicine-terrestrial and freshwater. USAEC Report TID-13358. VII, 138 p.; 1st Revision, V, 122 p. (1963); 2nd Revision, V, 129 p. (1965).

Schultz, V. 1966 References on Nevada Test Site ecological research. Great Basin Natur. XXVI:79-86.

Schultz, V., and A. W. Klement, Jr. 1963 Radioecology. Reinhold Publ. Corp. New York. 746 p.

Sellers, W. D. 1960 Arizona Climate. Univ. Ariz. Inst. Atmos. Phys. Univ. Ariz. Press. Tucson. 60 p.

Shantz, H. L. 1927 Drought resistance and soil moisture. Ecology 8:145-157.

Shantz, H. L. 1938 Plants as soil indicators. USDA Yearbook, Soils and Man. p. 835-860.

Shantz, H. L. 1940 Types of vegetation in Escalante Valley, Utah as indicators of soil conditions. USDA Tech. Bull. no. 713. 46 p.

Shantz, H. L. 1947 The use of fire as a tool in the management of brush ranges of California. Calif. Div. Forest. Sacramento.

Shantz, H. L., and R. L. Piemeisal 1924 Indicator significance of natural vegetation of the southwestern desert region. Jour. Agr. Res. 28:721-801.

Shantz, H. L., and R. L. Piemeisel 1940 Types of vegetation in Escalante Valley, Utah, as indicators of soil conditions. USDA Tech. Bull. no. 713. 46 p.

Shantz, H. L., and R. Zon 1924 Natural vegetation, grassland, and desert shrub. *In* Atlas of American Agriculture. The Physical Basis of American Agriculture. USDA. Washington, D.C.

Shellhorn, S. J. 1955 Studies of the seedling anatomy of *Larrea tridentata*. Master's Thesis, Univ. Ariz. (Tucson). 44 p.

Shellhorn, S. J., and H. M. Hull 1961 A six-dye staining schedule for sections of mesquite and other desert plants. Stain Tech. 36:69-71.

Shields, Lora M. 1958 A botanical study of nuclear effects at the Nevada Test Site, 1957. New Mexico Highlands Univ., Annual Report to USAEC.

Shields, Lora M. 1959 An appraisal of radiation effects on vegetation within the Nevada Test Site. IX Int. Bot. Congr., Proc. (abstr.) 2:33.

Shields, Lora M. 1959 Recovery of vegetation in the vicinity of ground zero sites. Jour. Colorado-Wyoming Acad. Sci. 4:30-31.

Shields, Lora M., and F. Drouet 1962 Distribution of terrestrial algae within the Nevada Test Site. Amer. Jour. Bot. 49:547-554.

Shields, Lora M., L. W. Durrell, and A. H. Sparrow 1961 Preliminary observations of radiosensitivity of algae and fungi in soils from the Nevada Test Site. Ecology 42:440-441.

Shields, Lora M., and L. J. Gardner 1961 Bioecology of the arid and semiarid lands of the southwest. AAAS, Southwestern and Rocky Mountain Div., Symp. 69 p.

Shields, Lora M., and W. H. Rickard 1960 A botanical study of nuclear effects at the Nevada Test Site, 1959. New Mexico Highlands Univ., Annual Report to USAEC.

Shields, Lora M., and W. H. Rickard 1960 Recovery of vegetation in the vicinity of ground zero at the Nevada Test Site. Ecol. Soc. Amer., Bull. (abstr.) 41:119.

Shields, Lora M., and W. H. Rickard 1961 A preliminary evaluation of radiation effects at the Nevada Test Site. p. 1387-1390. In Recent Advances in Botany. Univ. Toronto Press. Toronto, Canada.

Shields, Lora M., W. H. Rickard, and F. Drouet 1959 A botanical study of nuclear effects at the Nevada Test Site, 1958. New Mexico Highlands Univ., Annual Report to USAEC.

Shields, Lora M., and P. V. Wells 1962 Effects of nuclear testing of desert vegetation. Science 135:38-40.

Shields, Lora M., and P. V. Wells 1963 Recovery of vegetation in the vicinity of atomic target areas at the Nevada Test Site. p. 307-310. In V. Schultz and A. W. Klement, Jr. (eds.) Radioecology. Reinhold Publ. Corp. New York.

Shields, Lora M., P. V. Wells, and W. H. Rickard 1963 Vegetational recovery on atomic target areas in Nevada. Ecology 44:697-705.

Shively, S. B., and J. E. Weaver 1939 Amount of underground plant materials in different grassland climates. Univ. Neb. Conserv. Bull. no. 21.

Shown, L. M., R. F. Miller, and F. A. Branson 1969 Sagebrush conversion to grassland as affected by precipitation, soil, and cultural practices. Jour. Range Manage. 22:303-311.

Shreve, F. 1917 The establishment of desert perennials. Jour. Ecol. 5: 210-216.

Shreve, F. 1922 Conditions indirectly affecting vertical distribution on desert mountains. Ecology 3:269-274.

Shreve, F. 1924 Soil temperature as influenced by altitude and slope exposure. Ibid. 5:128-136.

Shreve, F. 1925 Ecological aspects of the deserts of California. Ibid. 6: 93-103.

Shreve, F. 1929 Changes in desert vegetation. Ibid. 10:364-373.

Shreve, F. 1931 Larrea divaricata, Die Pflanzenareale. 3 Reihe, Heft 1. Verlag von Gustav Fischer, Jena. p. 5-6.

Shreve, F. 1934 Rainfall runoff and soil moisture under desert conditions. Annals Assoc. Amer. Geog. 24:131-156.

Shreve, F. 1936 The plant life of the Sonoran Desert. Sci. Monthly 42:195-213.

Shreve, F. 1937 The vegetation of the Cape region of Baja California. Madroño 4:105-113.

Shreve, F. 1940 The edge of the desert. Yearbook Assoc. Pacific Coast Geographers 6:6-11.

Shreve, F. 1941 Desert investigations. Carnegie Inst. Wash., Yearbook 40:170-172.

Shreve, F. 1942 The desert vegetation of North America. Bot. Rev. 8:195-246.

Shreve, F. 1942 Grassland and related vegetation in northern Mexico. Madroño 6:190-198.

Shreve, F. 1944 Rainfall of northern Mexico. Ecology 25:105-111.

Shreve, F. 1951 Vegetation of the Sonoran Desert. Carnegie Inst. Wash. Publ. 591. 129 p.

Shreve, F., and A. L. Hindsley 1937 Thirty years of change in desert vegetation. Ecology 18:463-478.

Shreve, F., and T. D. Mallery 1933 The relation of caliche to desert plants. Soil Sci. 35:99-113.

Shreve, F., and I. L. Wiggins 1964 Vegetation and Flora of the Sonoran Desert. Stanford Univ. Press. Stanford, Calif. 2 vol., 1740 p.

Shuvalov, S. A. 1966 Geographic-genetic patterns in the development of desert-steppe and desert soils of the USSR. Soviet Soil Sci. 3:243-253.

Simonett, D. S. 1968 Potential of radar remote sensors as tools in reconnaissance geomorphic, vegetation and soil mapping. 9th Int. Congr. Soil Sci., Trans. (Adelaide, Australia) IV:271-280.

Sinclair, J. C. 1922 Temperatures of the soil and air in a desert. Monthly Weather Rev. 50:142-144.

Singer, M. J., and L. Hanson 1969 Lead accumulation in soils near highways in the twin cities metropolitan area. Soil Sci. Soc. Amer., Proc. 33:152-153.

Slack, C. R., and M. D. Hatch 1967 Comparative studies on the activity of carboxylase and other enzymes in relation to the new pathway of photosynthetic carbon dioxide fixation in tropical grasses. Biochem Jour. 103: 660-665.

Slatyer, R. O. 1957 The significance of the permanent wilting percentage in studies of plant and soil water relations. Bot. Rev. 23:585-636.

Slatyer, R. O. 1962 Methodology of a water balance study conducted on a desert woodland. (Acacia aneura F. Muell). Community in Central Australia. In Arid Zone Research—XVII. A History Land Use in Arid Regions. UNESCO, Paris. p. 15-26.

Slatyer, R. O. 1964 Efficiency of water utilization by arid zone vegetation. Ann. Arid Zone 3:1-12.

Slatyer, R. O. 1967 Plant-water relationships. Int. Ser. of Monogr. 2 Academic Press. London & New York. 366 p.

Slatyer, R. O. 1970 Carbon dioxide and water vapour exchange in Atriplex. leaves. p. 23-29. In R. Jones (ed.) Studies of the Australian Arid Zone—The Biology of Atriplex. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ. Canberra, Australia.

Smith, R. F. 1968 Mechanisms of eutrophication at south Lake Tahoe. Ecol. Soc. Amer., Bull. (abstr.) 49: 65.

Somogyi, L. P., and R. J. Romani 1964 Irradiation-induced textural change in fruits and its relation to pectin metabolism. Jour Food Sci. 29:366-371.

Spalding, V. M. 1904 Biological relations of certain desert shrubs. I. The creosote bush (Corvillea tridentata) in its relation to water supply. Bot. Gaz. 38:122-138.

Spalding, V. M. 1909 Distribution and movements of desert plants. Carnegie Inst. Wash. Publ. 113.

Sparks, D. R. 1968 Diet of black-tailed jackrabbits on sandhill rangeland in Colorado. Jour. Range Manage. 21:203-208.

Sparrow, A. H. 1962 The role of the cell nucleus in determining radiosensitivity. USAEC Report BNL 766 (T287).

Sparrow, A. H. 1965 Comparisons of the tolerances of higher plant species to acute and chronic exposures of ionizing radiation. Japan. Jour. Genet. 40:12-37.

Sparrow, A. H. 1966 Research uses of the gamma field and related radiation facilities at Brookhaven National Library. Radiat. Bot. 6:377-405.

Sparrow, A. H., K. P. Baetcke, D. L. Shaver, and Virginia Pond. 1968 The relationship of mutation rate per roentgen to DNA content per chromosome and its interphase chromosome volume. Genetics 59:65-78.

Sparrow, A. H., R. L. Cuany, J. P. Miksche, and L. A. Schairer 1961 Some factors affecting the responses of plants to acute and chronic radiation exposures. Radiat. Bot. 1:10-34.

Sparrow, A. H., and H. J. Evans 1961 Nuclear factors affecting radiosensitivity: I. The influence of nuclear size and structure, chromosome complement and DNA content. Brookhaven Symposia on Biol. 14:76-100.

Sparrow, A. H., M. Furuya, and S. S. Schwemmer 1968 Effects of X- and gamma radiation on anthocyanin content in leaves of Rumex and other plant genera. Radiat. Bot. 8:7-16.

Sparrow, A. H., and J. P. Miksche 1961 Correlation of nuclear volume and DNA content with higher plant tolerance to chronic radiation. Science 134:282-283.

Sparrow, A. H., and Leanne Puglielli 1969 Effects of simulated radioactive fallout decay on growth and yield of cabbage, maize, peas and radish. Radiat. Bot. 9:77-92.

Sparrow, A. H., Anne F. Rogers, and Susan S. Schwemmer 1968 Radiosensitivity studies with woody plants—I. Acute gamma irradiation survival data for 28 species and predictions for 190 species. Radiat. Bot. 8:149-186.

Sparrow, A. H., L. A. Schairer, and Rhoda C. Sparrow 1963 Relationship between nuclear volumes, chromosome numbers, and relative radiosensitivities. Science 141:163-166.

Sparrow, A. H., L. A. Schairer, Rhoda C. Sparrow, and W. F. Campbell 1963 The radiosensitivity of gymnosperms: I. The effect of dormancy on the response of Pinus strobus seedlings to acute gamma irradiation. Radiat. Bot. 3:169-173.

Sparrow, A. H., L. A. Schairer, and G. M. Woodwell 1965 Tolerance of Pinus rigida trees to a ten-year exposure to chronic gamma irradiation from cobalt-60. Ibid. 5:7-22.

Sparrow, A. H., R. C. Sparrow, K. H. Thompson, and L. A. Schairer 1964 The use of nuclear and chromosomal variables in determining and predicting radiosensitivities. Ibid. 5(Suppl.):101-132.

Sparrow, A. H., and G. M. Woodwell 1963 Prediction of the sensitivity of plants to chronic gamma radiation. Ibid. 2:9-26. In V. Schultz and A. W. Klement, Jr. (eds.) Radioecology. Reinhold Publ. Corp. New York. p. 257-270.

Sparrow, Rhoda C., and A. H. Sparrow 1965 Relative radiosensitivities of woody and herbaceous spermatophytes. Science 147:1449-1451.

Springer, M. E. 1958 Desert pavement and vesicular layer of some soils in the Lohontan Basin, Nevada. Soil Sci. Soc. Amer., Proc. 22:63-66.

Springfield, H. W. 1966 Germination of fourwing saltbush seeds at different levels of moisture stress. Agron Jour. 58:149-150.

Springfield, H. W. 1967 Percentage of filled fourwing saltbush seeds.

U.S. Forest Serv. Res. Note RN-81. 4 p.

Springfield, H. W. 1969 Temperatures for germination of fourwing saltbush. Jour. Range Manage. 22:49-50.

Springfield, H. W., and D. G. Bell 1967 Depth to seed fourwing saltbush. Ibid. 20:180-182.

Squire, N. M., and L. J. Middleton 1966 Behaviour of Cs^{137} on soils and pastures, a long-term experiment. Radiat. Bot. 6:413-423.

Standley, P. C. 1923 Trees and shrubs of Mexico. Contrib. U.S. Nat. Herb. 23:517-848.

Stark, N. 1966 Review of highway planting information appropriate to Nevada. Univ. Nev. Des. Res. Inst., Bull. B-7. 209 p.

Statler, G. D. 1967 Eurotia lanata establishment trials. Jour. Range Manage. 20:253-255.

Stein, O. L., and A. H. Sparrow 1963 The effects of chronic gamma irradiation on the growth of Kalanchoe var. "Brilliant Star." Radiat. Bot. 3: 207-222.

Steiner, A. A. 1968 Apparatus for the measurement of oxygen consumption by the root system of a plant. Plant and Soil 28:173-176.

Stevens, O. A. 1943 Russian thistle, life history and growth. No. Dakota Agr. Exp. Sta., Bull. 326. 20 p.

Stewart, O. C. 1951 Burning and natural vegetation in the United States. Geog. Rev. 41:317-320.

Stewart, O. C. 1954 Forest fires with a purpose. Southwest. Lore 20:42-45.

Stewart, W. D. P. 1966 Nitrogen Fixation in Plants. The Athlone Press, London.

Stewart, W. D. P. 1967 Nitrogen-fixing plants. Science 158:1426-1432.

Stewart, W. D. P., G. P. Fitzgerald, and R. H. Burris 1967 In situ studies on N_2 fixation using the acetylene reduction technique. Nat. Acad. Sci. (U.S.), Proc. 58:2071-2078.

Strain, B. R., and Valerie C. Chase 1966 Effect of past and prevailing temperatures on the carbon dioxide exchange capacities of some woody desert perennials. Ecology 47:1043-1045.

Strogonov, B. P. 1964 Physiological Basis of Salt Tolerance of Plants. Israel Program for Sci. Translations Ltd., Jerusalem. Translated by A. Poljakoff-Mayber and A. M. Meyer.

Svensson, G. K. 1966 The increasing ^{137}Cs level in forest moss in relation to the total ^{137}Cs fallout from 1961 through 1965. p. 539-546. In B. Aberg and F. P. Hungate (eds.) Radioecological Concentration Processes. Pergamon Press. Oxford.

Svensson, G. K., and K. Liden 1965 The transport of ^{137}Cs from lichen to animal and man. Health Phys. 11:1393-1400.

Tabler, R. D. 1968 Soil moisture response to spraying big sagebrush with 2,4-D. Jour. Range Manage. 21:12-15.

Tadmor, N. H., M. Evanari, and L. Shanan 1970 Runoff farming in the desert. IV. Survival and yields of perennial range plants. Agron. Jour. 62:695-699.

Taylor, S. E., and D. M. Gates 1969 Significance of leaf form, and energy exchange approach. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 216.

Taylor, W. P. 1936 Some effects of animals on plants. Sci. Monthly 43: 262-271.

Taylor, W. P., C. T. Vorhies, and P. B. Lister 1935 The relation of jackrabbits to grazing in southern Arizona. Jour. Forest. 33:490-498.

Thornber, J. J. 1909 Vegetation groups of the desert laboratory domain.

Carnegie Inst. Wash., Publ. no. 113. p. 103-112.

Tiedemann, A. R., and J. O. Klemmedson 1970 Nutrient availability in desert grassland soils under Mesquite (*Prosopis juliflora*) trees and adjacent open areas. Agron. Abstr. 1970, p. 163.

Tisdale, E. W. 1969 Ecotypic variation in shrub-steppe vegetation of the intermountain region of the USA. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 219.

Toole, E. H., S. B. Hendricks, H. A. Borthwick, and Vivian K. Toole 1956 Physiology of seed germination. Ann. Rev. Plant Physiol. 7:299-324.

Tregunna, E. B., and J. Downton 1967 Carbon dioxide compensation in members of the *Amaranthaceae* and some related families. Can. Jour. Bot. 45:2385-2387.

Tregunna, E. B., W. J. S. Downton, and J. S. Berry 1969 Variation of photorespiration among species. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 221.

Tschirley, F. H. 1963 A physio-ecological study of jumping cholla (*Opuntia fulgida* Engelm.) Ph. D. Thesis, Univ. Ariz. 100 p. Univ. Microfilms, Ann Arbor, Mich. (Diss. abstr. 63-6848).

Tschirley, F. H., and S. C. Martin 1961 Burroweed on southern Arizona rangelands. Ariz. Agr. Exp. Sta., Tech. Bull. 146. 34 p.

Tueller, P. T. 1969 Vegetation-soil patterns in the Great Basin, Nevada, USA. Int. Conf. Arid Lands in a Changing World, Abstr. (Tucson) June 3-13.

Tueller, P. T., J. H. Robertson, and B. Zamora 1971 The Vegetation of Nevada, A Bibliography. Nev. Agr. Exp. Sta., Bull. R 78. 31 p.

Turner, F. B. 1962 Some influences of an underground nuclear detonation on close-in populations of whiptailed lizards (*Cnemidorphorus tigris*) at the Nevada Test Site. Ecol. Soc. Amer., Bull. (abstr.) 43:124.

Turner, F. B. 1963 A mathematical model for time-specific relationships of I^{131} between food consumed and the thyroid burden. Ecol. Soc. Amer. Bull. (abstr.) 44:75.

Turner, F. B. 1963 Biotic communities of the Nevada Test Site (a review). Ecology 44:663-664.

Turner, F. B. 1963 Influence of a cratering device on close-in populations of lizards. (Project Sedan). USAEC Report PNE-224F. 35 p.

Turner, F. B. 1963 Quantitative relationships between fallout radioiodine on native vegetation and in the thyroids of herbivores. Health Phys. 9: 1241-1246.

Turner, F. B. 1965 Uptake of fallout radionuclides by mammals and a stochastic simulation of the process. p. 800-820. *In* A. W., Jr. (ed.) Radioactive Fallout from Nuclear Weapons Tests. USAEC Report CONF-765.

Turner, F. B. 1966 Growth rate of lizards (*Uta stansburiana*) exposed to chronic gamma radiation. p. 46-52. *In* G. A. Sacher (ed.) Radiation Effects of Natural Populations. Argonne Nat. Lab. Lemont, Ill.

Turner, F. B., and C. S. Gist 1965 Influence of a thermonuclear cratering test on close-in populations of lizards. Ecology 46:845-852.

Turner, F. B., G. A. Hoddenbach, and J. R. Lannom, Jr. 1965 Growth of lizards in natural populations exposed to gamma irradiation. Health Phys. 11:1585-1593.

Turner, F. B., G. A. Hoddenbach, and J. A. Lannom 1965 Growth of *Uta stansburiana* in four experimental areas at the Nevada Test Site. Ecol. Soc. Amer., Bull. (abstr.) 46:51.

Turner, F. B., and R. I. Jennrich 1966 The concentration of I^{131} in the thyroids of herbivores and a theoretical consideration of the expected frequency distribution of thyroidal I^{131} in a larger consumer population. p. 175-182. In B. Aberg and F. Hungate (eds.) Radioecological Concentration Processes. Pergamon Press. Oxford.

Turner, F. B., B. Kowalewsky, R. H. Rowland, and K. H. Larson 1963 Uptake of radioactive materials from a nuclear reactor by small mammals at the Nevada Test Site. Health Phys. 10:65-68.

Turner, F. B., and J. R. Lannom, Jr. 1968 Radiation doses sustained by lizards in a continuously irradiated natural enclosure. Ecology 49:548-551.

Turner, F. B., and W. E. Martin 1963 Food-chain relationships of iodine-131 following two nuclear tests in Nevada (Project Sedan). USAEC Report PNE-236F. p. 5-54.

Turner, F. B., P. A. Medica, J. R. Lannom, Jr., and G. A. Hoddenbach 1969 A demographic analysis of continuously irradiated and nonirradiated populations of the lizard, Uta stansburianna. Radiat. Res. 38:349-356.

Turner, F. B., P. A. Medica, J. R. Lannom, Jr., and G. A. Hoddenbach 1969 A demographic analysis of fenced populations of the whiptail lizard, Cnemidophorus tigris, in southern Nevada. Southwest Natur. 14:189-202.

Turner, F. B., R. H. Rowland, and R. A. Wood 1965 Radioactivity in jack rabbits after the Sedan test of 1962. USAEC Report UCLA 12-582. 26 p.

Turner, F. B., R. H. Rowland, and R. A. Wood 1966 Nuclear engineering and wildlife: radioactivity in jackrabbits after the Sedan test. Jour. Wildl. Manage. 30:433-443.

Turner, R. M., and J. R. Hastings 1969 Fluctuations in the establishment rate of a saguaro (Carnegiea gigantea) population may record past climatic conditions. Int. Conf. Arid Lands in a Changing World, Abstr. (Tucson) June 3 - 13.

Turrell, F. M. 1969 Thermal conductivity, xeromorphism, and thermodynamics in leaves. 11th Int. Bot. Congr., Abstr. (Seattle) Aug. 24 - Sept. 2. p. 223.

Tyner, E. H. 1967 Electron probe microanalysis of soils. Agron. Jour. 1967: 86.

Ungar, I. A. 1962 Influence of salinity on seed germination in succulent halophytes. Ecology 43:763-764.

Ungar, I. A. 1966 Salt tolerance of plants growing in saline areas of Kansas and Oklahoma. Ecology 47:154-155.

Ungar, I. A., W. Hogan, and M. McClelland 1969 Plant communities of saline soils at Lincoln, Nebraska. Amer. Midland Natur. 82:564-577.

UNESCO 1962 Arid Zone Research–XVIII. The Problems of the Arid Zone. Proc. of the Paris Symp. UNESCO, Paris. 481 p.

UNESCO 1965 Arid Zone Research–XXV. Methodology of plant ecophysiology in arid conditions. Proc. of the Montpellier Symp. UNESCO, Paris. 531 p.

U.S. Forest Service 1937 Range plant handbook. U.S. Gov. Print. Off. Washington, D.C.

Upson, A., W. J. Cribbs, and E. B. Stanley 1937 Occurrence of shrubs on range areas in southeastern Arizona. Ariz. Agr. Exp. Sta., Mimeo.

Van der Borght, O., and F. P. Hungate 1968 Absorption of ^3H_2O and ^{22}Na from saline soil layers by greasewood. USAEC Annu. Report (1967) BNWL-714. vol. 1, p. 8.20-8.22.

Van Dyne, G. M. 1968 Ecosystems, systems ecology, and systems ecologist. USAEC Report ORNL-3957. 40 p.

Van't Hof, J., and A. H. Sparrow 1963 Growth inhibition, mitotic cycle time and cell number in chronically irradiated root meristems of Pisum.

Radiat. Bot. 3:239-247.

Van't Hof, J., and A. H. Sparrow 1965 Radiation effects on the growth rate and cell population kinetics of actively growing and dormant root of *Tradescantia paludosa*. Jour. Cell Biol. 26:187-199.

Vegis, A. 1964 Dormancy in higher plants. Ann. Rev. Plant Physiol. 15: 185-224.

Vest, E. D. 1962 Biotic communities in the Great Salt Lake Desert. Inst. Env. Biol. Res., Ecol. and Epizool. Ser. no. 73, Univ. Utah.

Vest, E. D. 1962 The plant communities and associated fauna of Dugway Valley in western Utah. Ph. D. Thesis, Univ. Utah. 122 p. Univ. Microfilms, Ann Arbor, Mich. (Diss. abstr. 64-13, 726).

Vig, B. K. 1969 Studies with ^{60}Co-radiated guar (*Cyamopsis tetragonoloba*) (L.) Taub. Ohio Jour. Sci. 69:18-31.

Vlamis, J., et al. 1964 Nitrogen fixation by root nodules of western mountain mahogany. Jour. Range Manage. 17:73-74.

Vorhies, C. E., and W. P. Taylor 1933 The life histories and ecology of jackrabbits, *Lepus alleni* and *Lepus californicus* species in relation to grazing in Arizona. Ariz. Agr. Exp. Sta. Tech. Bull. no. 49:467-487.

Wagle, R. F., and J. Vlamis 1961 Nutrient deficiencies in two bitterbrush soils. Ecology 42:745-752.

Walker, R. B. 1970 Measurements of net assimilation in Douglas fir using the Koch cuvette. Amer. Soc. Plant Physiol., Abstr., Univ. Calif. (Berkeley) June 22-24.

Wallace, A. 1970 Water use by *Salsola kali* grown at different soil temperatures and at limiting soil moisture. Soil Sci. 110:146-149.

Wallace, A., and R. T. Ashcroft 1970 Significance of vapor in plant water economy. Advancing Frontiers of Plant Science 26:153-159.

Wallace, A., and R. T. Mueller 1968 Effect of chelating agents on the availability of ^{54}Mn to three different soils. Soil Sci. Soc. Amer., Proc. 32:828-830.

Wallace, A., and R. T. Mueller 1968 Effect of chelating agents on the availability of ^{54}Mn following its addition as carrier-free ^{54}Mn to three different soils. Soil Sci. Soc. Amer., Proc. 32:828-830.

Wallace, A., W. A. Rhoads, and E. F. Frolich 1968 Germination behavior of *Salsola* as influenced by temperature, moisture, depth of planting, and gamma irradiation. Agron. Jour. 60:76-78.

Wallace, A., E. M. Romney, R. T. Ashcroft 1970 Soil temperature effects on growth of seedlings of some shrub species which grow in the transitional area between the Mojave and Great Basin Deserts. BioScience 20: 1158-1159.

Wallace, A., E. M. Romney, and R. T. Mueller 1969 Effect of the phosphorus level on the micronutrient content of *Franseria dumosa*. Phyton 26:151-154.

Wallace, A., S. J. Toth, and F. E. Bear 1948 Influence of sodium on growth and composition of ranger alfalfa. Soil Sci. 64:477-486.

Waller, H. D., and J. S. Olson 1967 Prompt transfers of cesium-137 to the soils of a tagged *Liriodendron* forest. Ecology 48:15-25.

Walter, H. 1963 The water supply of desert plants. p. 199-205. *In* A. J. Rutter and F. W. Whitehead (eds.) The Water Relations of Plants. John Wiley & Sons, Inc. New York.

Waring, R. H., and B. D. Cleary 1967 Plant moisture stress: evaluation by pressure bomb. Science 155:1248-1254.

Warren, H. V., and R. E. Delavault 1960 Observations on the biochemistry of lead in Canada. Royal Soc. Can., Trans. Sec. IV 54:11-20.

Warskow, W. L. 1965 Factors affecting stomatal opening of creosotebush (*Larrea tridentata* [D.C.] Cov.) and their combined effect on herbicide activity. Master's Thesis, Univ. Ariz. (Tucson).

Waterfall, U. T. 1946 Observations on the desert gypsum flora of southwestern Texas and adjacent New Mexico. Amer. Midland Natur. 36:456-466.

Weaver, J. E., and F. E. Clements 1938 Plant Ecology. McGraw-Hill. New York.

Webster, S. R., et al. 1967 Fixation of nitrogen by bitterbrush (Purshia tridentata [Pursh] D.C.). Nature 216:392-393.

Wells, P. V. 1961 Succession in desert vegetation on streets of a Nevada ghost town. Science 134:670-671.

Wells, P. V. 1964 Pleistocene vegetation in the Mojave Desert: some wood rat midden evidence. Ecol. Soc. Amer., Bull. (abstr.) 45:76.

Wells, P. V., and C. D. Jorgensen 1964 Pleistocene wood rat middens and climate change in Mojave Desert: A record of juniper woodlands. Science 143:1171-1173.

Wells, P. V., and Lora M. Shields 1961 Disturbance and succession in desert vegetation on the Nevada Test Site of the USAEC. Ecol. Soc. Amer., Bull. (abstr.) 42:109.

Wells, P. V., and Lora M. Shields 1962 Distribution of Larrea in relation to a temperature inversion in Yucca Flat, Nevada. Ibid. 43:118.

Wells, P. V., and Lora M. Shields 1964 Distribution of Larrea in relation to temperature zonation at the Nevada Test Site. Southwest. Natur. 9: 51-55.

Went, F. 1968 The mobile laboratories of the Desert Research Institute. BioScience 18:293-297.

Went, F., and N. Stark 1968 The biological and mechanical role of soil fungi. Nat. Acad. Sci. (U.S.), Proc. 60:497-504.

Went, F. W. 1942 The dependence of certain annual plants on shrubs in Southern California deserts. Torrey Bot. Club, Bull. 69:100-114.

Went, F. W. 1948 Ecology of desert plants. I. Observations on germination in the Joshua Tree National Monument, California. Ecology 29:242-253.

Went, F. W. 1949 Ecology of desert plants. II. The effect of rain and temperature on germination and growth. Ibid. 30:1-13.

Went, F. W. 1953 The effects of rain and temperature on plant distribution in the desert. Res. Coun., Israel, Spec. Publ. 2:1-11.

Went, F. W. 1955 The ecology of desert plants. Sci. Amer. 192:68-75.

Went, F. W. 1966 On the nature of Aitken condensation nuclei. Tellus XVIII: 549-555.

Went, F. W., G. Juhren, and M. C. Juhren 1952 Fire and biotic factors affecting germination. Ecology 33:351-364.

Went. F. W., and M. Westergaard 1949 Ecology of desert plants. III. Development of plants in the Death Valley National Monument, California. Ibid. 30:26-38.

West, K. R. 1970 The anatomy of Atriplex leaves. p. 11-15. In R. Jones (ed.) Studies of the Australian Arid Zone—The Biology of Atriplex. Div. Plant Ind., Commonwealth Sci. Ind. Res. Organ. Canberra, Australia.

West, Marda L. 1969 Physiological ecology of three species of Artemisia in the White Mountains of California. Ph. D. Thesis, Univ. Calif., Los Angeles. 100 p. Univ. Microfilms, Ann Arbor, Mich. (Diss. abstr. 70-8221).

West, N. E. 1969 Regenerative adaptations of native perennial chenopods to cold deserts of Western North America. 11th Int. Bot. Congr., Abstr. Aug. 24 - Sept. 2. p. 236.

West, N. E. 1969 Soil-vegetation relationships in arid southeastern Utah. Int. Conf. Arid Lands in a Changing World, Abstr. (Tucson, Ariz.) June 3 - 13, 1969.

Whaley, W. G. 1952 Arid lands and plant research. Sci. Monthly 75:228-233.

Whicker, F. W., G. C. Farris, E. E. Remmenga, and A. H. Dahl 1965 Factors influencing the accumulation of fallout ^{137}Cs in Colorado mule deer. Health Phys. 11:1407-1414.

Whitfield, C. J., and E. L. Beutner 1938 Natural vegetation in the desert plains grassland. Ecology 19:26-37.

Whitman, P. C., and D. Koller 1964 Saturation deficit of the mesophyll evaporating surfaces in a desert halophyte. Science 146:1320-1321.

Whittaker, R. H. 1962 Classification of natural communities. Bot. Rev. 28:12-39.

Whittaker, R. H., and W. A. Niering 1964 Vegetation of the Santa Clara Mountains, Arizona. I. Ecological classification and distribution of species. Jour. Ariz. Acad. Sci. 3:9-34.

Whittaker, R. H., and W. A. Niering 1965 Vegetation of Santa Catalina Mountains, Arizona: A gradient analysis of the south slope. Ecology 46:429-452.

Wight, J. W., and J. T. Nichols 1966 Effects of harvester ants on production of a saltbush community. Jour. Range Manage. 19:68-71.

Wilson, J. H. 1893 Leaves and stipules of Larrea mexicans Moric. Bot. Soc. Edinburgh, Proc. 19:185-190.

Wilson, R. E., and E. L. Rice 1968 Allelopathy as expressed by Helianthus annus and its role in old-field succession. Torrey Bot. Club, Bull. 95: 432-448.

Witkamp, M., and Marilyn L. Frank 1967 Cesium-137 kinetics in terrestrial microcosms. 2nd Nat. Symp. Radioecol., Proc. (Ann Arbor, Mich.) May 15 - 17. p. 635-651.

Witkamp, M., and Marilyn L. Frank 1969 Loss of weight, cobalt-60, and cesium-137 from tree litter in three subsystems of a watershed. Environ. Sci. Technol. 3:1195-1198.

Wlodek, S. 1966 The behaviour for ^{137}Cs in freshwater reservoirs, with particular reference to the reactions of plant communities to contamination. p. 897-912. In B. Aberg and F. P. Hungate (eds.) Radioecological Concentration Processes. Pergamon Press. Oxford.

Woodell, S. R. J., H. A. Mooney, and A. J. Hill 1969 The behavior of Larrea divaricata (creosotebush) in response to rainfall in California. Jour. Ecol. 57:37-44.

Woodwell, G. M. 1961 Design of the Brookhaven experiment on the effects of ionizing radiation on a terrestrial ecosystem. USAEC Report BNL-6672.

Woodwell, G. M. 1962 Effects of ionizing radiation on terrestrial ecosystems. Science 138:572-577.

Woodwell, G. M. 1963 Effects of ionizing radiation on terrestrial ecosystems. Sci. Amer. July 1963.

Woodwell, G. M. 1965 Radiation and the patterns of nature. USAEC Report BNL-924. 15 p.

Woodwell, G. M. 1970 Effects of pollution on the structure and physiology of ecosystems. Science 168:429-433.

Woodwell, G. M., F. R. Becherer, and E. B. Hadley 1966 The productivity of natural communities. I. An automatic data recording system for monitoring metabolism and microclimate in the field. USAEC Report BNL-7901. 30 p.

Woodwell, G. M., and L. N. Miller 1963 Chronic gamma radiation affects the distribution of radial increment in Pinus rigida stems. Science 139: 222-223.

Woodwell, G. M., and A. H. Sparrow 1962 Predicted and observed effects of chronic gamma radiation on a near-climax forest ecosystem. USAEC Report BNL-6968.

Woodwell, G. M., and A. H. Sparrow 1965 Effects of ionizing radiation on ecological systems. p. 20-38. In Ecological Effects of Nuclear War. USAEC Report BNL-917 (C-43).

Wooton, E. O. 1895 The Russian thistle. New Mex. Agr. Exp. Sta., Bull. 16. 20 p.

Wright, R. D. 1963 Some ecological studies on bristlecone pine in the White Mountains of California. Ph. D. Thesis, Univ. Calif., Los Angeles. 118 p.

Wright, R. D., and H. A. Mooney 1965 Substrate oriented distribution of bristlecone pine in the White Mountains of California. Amer. Midland Natur. 73:257-284.

Yamakawa, K., and A. H. Sparrow 1965 Correlation of interphase chromosome volume and reduction of viable seed set by chronic irradiation of 21 cultivated plants during reproductive stages. Radiat. Bot. 5:557-566.

Yamakawa, K., and A. H. Sparrow 1966 The correlation of interphase chromosome volume with pollen abortion induced by chronic gamma irradiation. Ibid. 6:21-38.

Yang, T. W. 1951 Distribution of Larrea tridentata in the Tucson area as determined by certain physical and chemical factors of the habitat. Master's Thesis, Univ. Ariz. (Tucson). 47 p.

Yang, T. W. 1957 Vegetational, edaphic, and faunal correlations of the western slope of the Tucson Mountains and adjoining Arva Valley. Ph.D Thesis, Univ. Ariz. (Tucson). 154 p. Univ. Microfilms, Ann Arbor, Mich. (Diss. abstr. 24,544).

Yang, T. W. 1961 The recent expansion of creosotebush (Larrea divaricata) in the North American Desert. Western Res. Acad. Nat. Hist. Muse. Spec. Publ. no. 1 (Hudson, Ohio). 11 p.

Yang, T. W. 1967 Chromosome numbers in populations of creosotebush (Larrea divaricata) in the Chihuahuan and Sonoran subdivisions of the North American Desert. Jour. Ariz. Acad. Sci. 4:183-184.

Yang, T. W. 1967 Ecotypic variation in Larrea divaricata. Amer. Jour. Bot. 54:1041-1044.

Yang, T. W. 1968 A new chromosome race of Larrea divaricata in Arizona. Western Res. Acad. Natur. Hist. Muse. Spec. Publ. 2 (Hudson, Ohio). 4 p.

Yang, T. W., and C. H. Lowe, Jr. 1956 Correlations of major vegetation climaxes with soil characteristics in the Sonoran Desert. Science 123: 542.

Yang, T. W., and C. H. Lowe 1968 Chromosome variation in ecotypes of Larrea divaricata in the North American Desert. Madroño 19:161-164.

Yule, G. U. 1912 On the methods of measuring association between two attributes. Jour. Roy. Statist. Soc. 75:579-642.

Zakhar 'yants, I. L., and A. S. Ionesova 1966 Photosynthesis in desert plants in association with their carbohydrate metabolism. Mater. Fiziol. Ekol. Rast. Sredn. Azii (Tashkent. Fan) 70-76 (Russ.). Cf. Chem Abstr. 66:112971m (1967).

This list contains references pertiment to our work at the Nevada Test Site and is more extensive than the references quoted in the text.